The What and How of Smart Personal Assistants: Principles and Application Domains for IS Research

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Abstract. Digitization brings new possibilities to ease our daily life activities by the means of assistive technology. Amazon Alexa, Microsoft Cortana, Samsung Bixby, to name only a few, heralded the age of smart personal assistants (SPAs), personified agents that combine artificial intelligence, machine learning, natural language processing and various actuation mechanisms to sense and influence the environment. However, SPA research seems to be highly fragmented among different disciplines, such as computer science, human-computer-interaction and information systems, which leads to 'reinventing the wheel approaches' and thus impede progress and conceptual clarity. In this paper, we present an exhaustive, integrative literature review to build a solid basis for future research. We have identified five functional principles and three research domains which appear promising for future research, especially in the information systems field. Hence, we contribute by providing a consolidated, integrated view on prior research and lay the foundation for an SPA classification scheme.

Keywords: Smart Personal Assistants, Context-awareness, Literature Review

1 Introduction

The digital age brings new possibilities to ease many activities of our daily life. Modern systems that assist us conducting particular tasks, we refer to them as Smart Personal Assistants (SPA), rely on emerging technologies, such as natural language processing and artificial intelligence. They pave the way for increased quality in private life and work, while the meaning of 'quality' depends on the user's context: in work environments, adaption to tasks and individuals' characteristics may lead to increased productivity and safety for physically demanding jobs. In a private context, however, SPAs such as Google Assistant, Amazon Alexa, Microsoft Cortana or Samsung Bixby are designed to increase users' comfort and livability. Recent studies show that these systems are increasingly becoming part of many people's everyday lives: the worldwide number of SPA users is expected to grow from 390 million in 2015 to 1.8 billion in 2021 which will result in a total revenue increase from $1.6 billion to $15.8 billion [1]. Thereby, current use cases for SPA are manifold and range from reciting weather information to (autonomously) operation smart home devices [2].

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Although the development and dissemination of SPAs has just gained momentum due to the launch of Amazon Echo products running Alexa, IS research seems to just recently discover the objectified combination of artificial intelligence (AI), machine learning, voice recognition and other recent technologies as promising research area. This is surprising, since assistive technology is far from being a novel topic. For example, assisted driving has already leveraged many potentials of digital technologies and is now reinventing itself by the means of AI and machine learning. From a research perspective, much ‘groundwork’ has been conducted in the fields of formal and applied computer science, e.g., by investigating and developing intelligent agents [3]. Furthermore, human-computer interaction (HCI) research has analyzed user behavior towards SPAs that offer multiple forms of interaction [4, 5].

However, since the core of the information systems (IS) discipline is concerned with information technology in use [6], we argue that it is able to make great contributions to SPA research by mining theoretical, empirical and design knowledge. Hence, the purpose of this paper is to establish a common and solid foundation for future SPA research in IS. Therefore, we conducted a systematic literature review and present selected findings, i.e., fundamental principles and domains where further research appears to be promising. With our review, we contribute to IS but also to adjacent disciplines by providing an integrative view on what is now and next in SPA research. Since especially recent research is inextricably linked with current practical advancements, our work may also help practitioners to obtain lexical clarity as well as an overview on opportunities and open questions regarding SPAs.

The paper is structured as follows. Section 2 introduces the basic concepts and terms around SPAs that guide our literature review which is described in section 3. We present our findings, namely basic principles and application domains, in section 4 and discuss them along with additional unanswered questions in section 5. We conclude with limitations and an outlook to future research in section 6.

2 Smart Personal Assistants

Although SPAs – especially for private purposes – are a very new development, they relate their smartness to certainly not new concepts. One constituting factor of SPAs is context-awareness. Context according to Dey and Abowd [7, p. 3 f.] *“is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves”*. In order to improve the interaction between humans and computers, context-aware computing (i.e., a system’s using of context to provide relevant information and tailored services to humans) presents a promising method to support individuals in daily life [8].

Today, the implementation of context-aware computing is possible via personal assistants known as User Assistance Systems, virtual agents or SPAs, such as Google Assistant, Amazon Alexa, Microsoft Cortana or Samsung Bixby. Although they all belong to the class of context-aware systems, there are considerable differences between them. Maedche et al. [8] suggest a classification based on two dimensions: (1)

the degree of intelligence of the system and (2) the degree of interaction implemented by the system. In contrast to basic systems characterized by a low degree of interaction and low degree of intelligence, advanced systems are characterized by more sophisticated features. They allow users to decide whether to follow the assistance, provide a high extent of context-aware and proactive assistance, include adaptation capabilities, and detect users' needs [8].

In this paper, we mainly focus on anticipating systems because the aforementioned SPAs heavily rely on context information, anticipation and rich interaction. Such systems are characterized by high degrees of both intelligence and interaction and can be distinguished from basic systems by a high degree of context awareness as well as a high dialogue competency. On top of that, they anticipate future situations and adapt their capabilities to the needs of the users and their situations.

There are also other features which can be used to delimit SPAs. For instance, Purington et al. [9] examined Amazon's Alexa on the basis of four different dimensions including degree of personification, degree of sociability, integration and technical qualities and issues. The degree of personification refers to the extent to which the technology is personified by the user. The degree of sociability is the extent of interaction. Integration is the system's ability to connect with other entities. Finally, technical qualities and issues refer to the performance of the system's tasks, e. g., the extent to which the system gives intelligent responses to humans' voice requests. However, further steps are needed for conceptualizing SPA principles and domains.

3 Method

To identify functional principles and outline application domains, we conducted a systematic literature review [10, 11]. According to Cooper's taxonomy [12], we focus on outcomes of SPA research papers, their underlying theories and practical applications. The goal of the review is to find principles and application domains by integrating prior findings using a concept matrix for literature organization. Given this goal, we do not espouse any position and provide a neutral perspective on the status-quo to general and specialized scholars in the field of SPA research. Furthermore, our literature review is exhaustive since we conducted open database searches. However, it is also selective to the field of IS, the scope of our research, and rules for in- and exclusion of articles as described below. The literature search was conducted in September 2017. A prior informal literature search revealed keywords for the open database searches [8, 9, 13–15] which resulted in the search phrase ("smart assistant" OR "conversational agent" OR "virtual assistant" OR "assistance system" OR "personal assistant"). The phrase was adapted to fit databases' syntactic requirements. The open database search was constrained to title, abstract, keywords and a publication period from 2000 to date. Databases include *AISeL*, *EBSCO Business Source Premier*, *ScienceDirect*, *IEEE Xplore*, *ACM DL* and *ProQuest* as common for IS, HCI and computer science. The open search resulted in 2802 hits. Titles, abstracts and keywords were screened regarding potential fit to the purpose of the study. In detail, articles are explicitly included if they relate to the substance of IS and either fit or contribute to (i.e., extend, challenge, detail) our understanding of principles and application domains. Articles are explicitly excluded if they refer to distinct research fields such as assisted or autonomous driving (e.g., ecodriving), technical assistance for children, elderly or impaired (e.g., computer-generated voice for speechless), non-technical assistants (e.g., human personal teachers) or assistive systems in a sociological or political meaning (e.g., social assistance). However, since we are aware that including such articles may be promising for the advance of research on smart assistants, we briefly touch connections to the core of our study in the discussion section. We furthermore excluded rather technical descriptions (e.g., the development of SPA architectures) and formal models for SPA (component) development (e.g., formalized functioning of multi-layer voice recognition components). Screening was conducted by two researchers independently and resulted in 354 articles that appeared relevant for our goal. By thoroughly reading the full texts, the number of contributions has further been reduced to a manageable amount of 185. A backward and forward search as well as an open search on Google Scholar confirmed our assumption that our review results are saturated and computer science, IS and HCI articles are sufficiently represented. Table 1 lists the number of search results after each review phase.

Table 1. Literature search results[1]

Database	*Total hits*	*After Screening*	*Relevant*
AISeL	26	20	14
IEEE XPlore	1074	110	62
ACM DL	800	123	53
EBSCO Business Source Premier	136	27	14
ScienceDirect	672	63	41
ProQuest	94	11	1
Total	**2802**	**354**	**185**

Two independent researchers derived SPA principles and application domains by first identifying specific SPA mechanics and use cases which were further clustered, generalized, compared, discussed, and unified. Due to space limitations, we cannot illustrate each of the 185 articles. Hence, we demonstrate our core results, i.e., principals and application domains, providing reference to representative papers.

4 Results

4.1 Principles of Smart Personal Assistants

Context-awareness. While clarity of the term context-awareness suffers from vague definitions and understandings of context, most work on SPAs (inherently or explicitly) claim that identification, processing and use of contextual information are substantial

[1] A concept matrix that provides a detailed list of the reviewed articles and relations to our results is available at: http://downloads.wi-kassel.de/MKWI18/Knote_et_al_Appendix.pdf

to refer to these class of systems as ‘smart’ assistants. Based on prior definitions [7, 16–18], we understand context as all aspects of an entity’s (i.e., a person’s, place’s or object’s) physical and logical environment. This may comprise various properties that can be captured by sensors, such as location, temperature, humidity, calendar entries or other entities nearby. Hence, a context-adaptive system is able to detect and react to context (changes) by taking appropriate actions. In addition, a system is context-adaptive, *“if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user’s task.”* [7, p. 6]

For the case of SPAs, *context detection* is usually enabled by acoustical and/or optical sensors, such as microphones and/or cameras, which are often combined with GPS, temperature or humidity sensors. Being part of a ‘social network’ of objects (e.g., smart home appliances) and people [19], data communicated to an SPA can also be considered context information, as they may help form a picture of the environment. Since SPAs are designed to support people conducting a particular task [8], personal data is often collected (e.g., filtered from voice commands) and used to provide assistance which is individualized to the user’s habits, abilities, preferences, goals and intentions [20]. This, however, leads to yet unresolved security, privacy and trust concerns which, according to the well-known causal relationship between distrust and lower levels of IT artifact use, is likely to impede SPA success [21]. To investigate *context reaction* of SPAs, it appears useful to distinguish between *what* is subject to reaction and *how* this reaction appears. While the subject of SPA actions usually depends on the task the user is assisted in (see section 4.2), reaction appearance is dependent on given hardware and software actuators (which in turn is related to the system’s embodiment and multimodality), self-evolution capabilities and deepness of entity network or platform integration. Hence, a myriad of possible reactions exists, including voice and/or interface responses [3], smart objects control [22], purchase process activation [13] and other combination that assist users in a particular task.

Self-evolution. Many authors refer to SPAs using the word ‘agents’ [e.g.,4, 5, 14, 15]. Apparently, these contributions especially aim to point out the SPA as an autonomous entity which is capable of perceiving and taking actions within its environment to achieve a certain goal [23], which in this context is to assist the user conducting a specific task. However, the ways how these systems attempt to achieve their goal heavily vary. Russel and Norvig provide a classification scheme for intelligent agents which comprises five groups depending their capabilities: simple reflex agents, model-based reflex agents, goal-based agents, utility-based agents and learning agents [23]. While all agents are able to autonomously detect and take actions within their environment, simple reflex agents do so by applying a set of ‘if-then rules’ to determine suitable actions for the detected situation. Model-based reflex agents add complexity through a model, which is explaining and predicting ‘how the world works’. Although this allows the agent for rudimental self-reflection, it chooses an action in the same way as a simple reflex agent. Goal-based agents additionally hold a set of desirable outcomes and thus may choose an action which reaches the goal state. On top of this, utility-based agents allow for differentiated measures on how desirable a goal state is. It chooses an action based on its utility function as it compares the current and stored alternative states. However, although these approaches provide appropriate logics for rather predictive and observable environments, unexpected effects can be handled through goal or utility models as they follow a predefined set of possible conditions (i.e., 'the reality'). In case unknown context variables are detected or known variables attain yet unknown values, the system should be flexible enough to dynamically adapt its behavior according to the 'critic' on how it performs (i.e., self-evolution). Hence, learning agents contain a separate learning element which is responsible for behavior adaptation, while the performance element chooses which actions to take.

The results of our review show, that in the last few years, an increasing number of SPAs have appeared that can (at least to some degree) be considered learning agents. Taking Amazon's Alexa as a prominent example, the agent handles opaque utterances with lexical approximation. If the user does not disconfirm to Alexa's response, the SPA's learning unit stores new pronunciation characteristics and thus evolutes its natural language processing abilities. However, AI research on self-evolution mechanisms is still in its infancy but is currently gaining momentum through the success of SPAs and advances in machine learning.

Multimodality. Authors often classify SPAs according to their dominant mode of interaction (e.g., conversational agents [4] or voice and vision personal assistant [24]). Our results reveal, that many SPAs are referred to as multimodal, meaning the ability to receive input and/or deliver output in more than one way [4]. In most SPAs, graphical user interfaces (GUIs) are combined with voice recognition and natural language processing abilities [3]. However, there is a multitude of possible interaction behaviors which an SPA might employ, such as eye motion, gestures, facial expressions or even emotional or cognitive states [4, 25]. The major goal of multimodality is to combine signals different from different communicative channels so that users impute a certain degree of intelligence or smartness to the SPA which thus leads to greater comfort and enjoyment due to entirely new possibilities (e.g., hands-free smart home control) [4]. Multimodality can either be implemented in a unidirectional or a bidirectional manner. Unidirectional multimodality implies, that SPAs may either receive input via different channels but can only respond or take actions via a single actuator (e.g., gesture and cognitive state input, voice output) or vice versa (e.g., voice input, output by controlling smart objects, voice and facial expression). Bidirectional multimodality combines different input modes with a multitude of output modes. However, our results show that multimodality is intertwined with anthropomorphism and context-awareness. For example, in order to respond to a voice command with a friendly smile, the detectability and interpretability of spoken natural language is an equally important prerequisite as it is the appropriate representation of a smile on an artificial human face [5].

Anthropomorphism. Further, literature proposes anthropomorphism to be an additional key principle of SPAs, referring to the assistant aspect of the SPA [26], that is *"a conscious mechanism wherein people infer that a non-human entity has human-like characteristics and warrants human-like treatment"* [9, p. 2854]. The degree of anthropomorphism might differ heavily in SPAs, also depending on the provided user interface. When considering SPAs like Alexa or Siri, that focus on voice almost alone, research around the theme of conversational agents tended to the already mentioned multimodal developments, with a focus upon anthropomorphism and embodiment with virtual characters [4]. Anthropomorphism raises the expectations of more human behavior and responses [21]. For instance, several studies found first evidence for that human-like features of Siri or Alexa make users assign human traits to their IT artifacts and also making them more user friendly [9, 21]. However, such a humanness also may lead to unrealistic expectations of the systems capabilities and, thus, leading to dissatisfaction when expectations are not met [4, 21]. Attached to these discussions are virtual characters, their embodiment and according emotions in SPAs. While a lot of past research focused on interactive characters with a varying degree of similarity to humans, i.e., from cartoon-like characters to virtually human-like characters [27], also robots are used for the embodiment of human-like characteristics [28]. To implement such characteristics, research focused on delivering natural gestures with virtual characters [29], affective emotions based on user behavior [30] or humor [31] that is also a significant component of systems like Siri and Alexa [4].

Platform integration and extensibility. While for example Alexa is certainly designed from scratch with an ecosystem integration, other products as well as areas of application (see in the next section) lack such forms of integration, thus, frustrating customers. For example, the study of Cowan et al. points out that Siri is very limited to the Apple ecosystem and opening by default only Apple apps while also being limited to Apple devices [21]. However, rich ecosystems enable new affordances for an integration of SPAs [22], especially when considering Internet of Things (IoT) solutions like smart home appliances or smart shopping like the Amazon dash button, where the SPA takes a stationary hub position in the service ecosystem. Though, such new affordances also raise questions concerning forensics and other legal questions. As such, multimodality and "always-on" features as well as its integration in the cloud ecosystem highlight that confidentiality of data is very vulnerable [32].

4.2 Application Domains of Smart Personal Assistants

Daily life and family. The revolution of SPAs was essentially influenced by their use in private life, e.g., for tourism, shopping or smart home purposes. Early IS research focused especially on shopping and e-commerce with the concepts of recommendation agents and according algorithms to assist shopping tasks and make them more productive [e.g., 27], while also focusing on the consequences for trust development as well as technology adoption [15]. A special case of commerce is tourism that greatly profits from gathering contextual data supplied by various databases and ecosystems to provide more in-situ support in traveling new places [33]. Recently, IS research also took mobile shopping assistants into account while showing that technologies like RFID are more favorably in terms of technology adoption while they also imply perceptions of security risks [13]. This certainly applies also to the case of smart homes where the multimodality and ecosystem integration offers new affordances that also relate to privacy issues. Though, such approaches have potential to make life more convenient, especially for elderly people and the case of assisted living [22].

Work support. Great potentials are anticipated in practice and research for using SPAs in supporting work processes. As such, in manufacturing systems, human errors in critical situations are avoided by extending the intelligence of humans in order to make informed decisions [34]. This is especially prevalent when considering heterogenous worker types, e.g., freshmen, experienced and impaired workers that present specific challenges for the workplace that could be supported by SPAs [35]. While freshmen and impaired workers might profit from direct assistance, experienced workers can qualify for more demanding jobs, thus changing the role how we work. SPAs could take a significant and coordinating role in cyber-physical systems and profit from the smartness of the workplace [36]. Though, when taking obligations into account, the massive account of collected personal data in the workplace might be used for purposes of worker assessment, failure rates etc., as such privacy-related issues of these invasive technologies in the workplace arise [37].

E-Learning. Another important domain is the application of SPAs in different roles for the purpose of learning that is supplemented by IT, i.e., E-Learning. Possible application examples can be derived from concepts such as scaffolding or tutoring [38], where learning processes of individuals are supported by the active use of IS, for example directly in the work-process. A typical example is manufacturing supplemented by SPAs for maintenance purposes [39]. Workers are supported in maintaining a machine while the SPA also supports the worker to learn special procedures in the maintenance process, dependent on prior knowledge. When considering the principles of SPAs, context-awareness is therefore oftentimes derived concerning dispositional factors of the individual such as prior knowledge and needed support level but also dependent on the work process [40]. When considering self-learning capabilities, SPAs might rely on learning analytics that adapt and learn on the basis of formative assessments to provide for example guidance in the learning process or stress relief in exams [41]. Although multi-modality is rarely considered for learning purposes, there are solutions for considering augmented [42] or more simple approaches to learn with SPAs such as QR-codes [43, 44]. Concerning anthropomorphism, SPAs in the learning domain are oftentimes designed with avatars that embody cartoon characters to avoid similarities with teachers and convey a gamified support. In contrast, SPAs in other contextual situations also often embody a human-like educator to convey a more personal, serious and affective way in teaching [30, 44].

5 Discussion

The goal of our review was to provide an overview on functional SPA principles and promising application domains for IS research. Hence, we conclude that there is rapid development in the topic and hope, that IS researchers hold the pace of advancements in HCI and computer science. However, there are also numerous unanswered questions, to which IS is predestined to find answers. First, IS can be the perfect nucleus to research on the balance between assistance, agency and autonomy of digital entities and possible effects to individuals and the society. While assistance, i.e., supporting humans to conduct particular tasks, is currently acknowledged as higher-order goal, agency may also mean to operate in the user's stead, which can be desirable in dangerous, hazardous and risky environments, but may be of unpredictive outcome in cooperative tasks. Thus, balancing autonomy, as the degree to which a system is self-operating and self-evolving (i.e., self-evoluting) and controllability is a highly situation and task-specific endeavor which calls for further research effort. Second, a multitude of questions regarding privacy, security and trust towards SPAs remain yet unanswered [45]. Our review reveals further several blind spots, e.g., the consideration of platforms and ecosystems for the use of SPAs in various application domains. When taking a look at Amazon Alexa and the Echo ecosystem, it is kind of obvious that the SPA is centered around a vivid ecosystem that includes various parties (e.g., skill creators, hardware developers, or car manufacturers with own ecosystems) in the value creation process, thus, building a strong service system. Third, questions arise, why the success of SPAs for private use did began with Alexa and not with the first-mover Siri. Cowan et al. offer an interesting thought that relate to the mobile use of Siri and the barriers of social embarrassment when using SPAs in the public [21]. That may not relate to the success of stationary settings such as Alexa and other SPAs in work settings. Last but far not least, there is still no consensus about how anthropomorphic SPAs and robots may be, so they are accepted by a wide variety of users and do not scare or frighten them [21].

6 Limitations, Future Research and Conclusion

Our review paper is in conclusion not without limitations. We excluded well-established research fields, e.g., assisted driving or support for the impaired, although we believe, that IS can learn from advances in these fields, i.e., when taking the SPA principles for everyday application into account. Additionally, we are aware that this classification is only one way how to structure research on SPAs and reflects a discussable basis. However, we have made the first systematic step with respect to existing authorities and contribute by bringing a certain conceptual clarity and highlighting whitespots regarding SPA research. Our principles must be understood as continuums for characteristic attributes. Hence, in each category, different nuances or sub-categories exist, which must further be distinguished to establish a taxonomy and classify existing SPAs according to their attributes by future research. Our paper provides a first summary of research and a systematic approach to generalize findings from IS, HCI, computer science and other fields. Hence, we contribute to understanding this new class of IT artifacts and, thus, offer starting points for future IS research

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