The Smart Mobile Application Framework (SMAF) – Exploratory Evaluation in the Smart City Context

Mario Nadj[1,4], Felix Haeußler[1], Stefan Wenzel[2,4], and Alexander Maedche[3]

[1] University of Mannheim, Institute of Enterprise Systems (InES),
{nadj; haeussler}@es.uni-mannheim.de

[2] University of Bamberg, Faculty of Information Systems and Applied Computer Sciences,
stefan.wenzel@uni-bamberg.de

[3] Karlsruhe Institute of Technology, Institute of Information Systems and Marketing (IISM),
alexander.maedche@kit.edu

[4] SAP SE, Walldorf, {mario.nadj; stefan.wenzel}@sap.com

Abstract

What makes mobile apps "smart"? This paper challenges this question by seeking to identify the inherent characteristics of smartness. Starting with the etymological foundations of the term, elements of smart behavior in software applications are extracted from the literature, elaborated and contrasted. Based on these findings we propose a Smart Mobile Application Framework incorporating a set of activities and qualities associated with smart mobile software. The framework is applied to analyze a specific mobile application in the context of Smart Cities and proves its applicability for uncovering the implementation of smart concepts in real-world settings. Hence, this work contributes to research by conceptualizing a new type of application and provides useful insights to practitioners who want to design, implement or evaluate smart mobile applications.

1 Introduction

Every week another 1.3 million people move from rural areas in order to settle in a city (United Nations 2007). This development imposes significant challenges on today's city infrastructures and resources, e.g. with respect to transportation or citizen service provision. The Smart City groups a multitude of initiatives with information technology (IT) at their core to encounter the issues of future metropolitan areas (Giffinger 2007). "Smart Mobile Apps" (SMA) are one major element of Smart Cities, used to improve and simplify the life of urban citizens. Thereby we define SMAs as mobile IT-based applications providing distinct smart services for users. They are labeled as "smart" as they help users via their internal logic to solve arising problems while assuring a simple and safe usage (Schlachtbauer et al. 2012). While we become familiar with the term "smart", its meaning remains inconsistent. When being asked about smartness in smart devices, both laymen and experts name a blend of concepts such as connectivity, autonomy, sensors, communication, supportiveness, individual empowerment, cloud computing and context awareness (Gandhi and

Robbins 2015). While the individual concepts and technologies are well known, we observe a research gap where these technologies are combined to enable SMAs. Therefore, the objective of this paper is to narrow down the emerging research gap, and to open up opportunities for further research in this discipline. Two concise research objectives can be distinguished: (1) To conceptualize SMAs by identifying their underlying constituents and (2) to explore how SMAs may be implemented in the Smart City context by leveraging smart concepts. Researchers benefit from this conceptualization in multiple ways: First, researchers can more immediately investigate distinct aspects of smartness by building on or adapting the proposed conceptualization. Second, this conceptualization could present a starting point for a more vivid discourse about smartness in IT. Third, the framework might support practitioners to analyze existing applications for the use of smart concepts in order to derive requirements for their own application or to benchmark own developments against those of competitors.

2 Smartness

Smartness is a new buzzword to "describe technological, economic and social developments fuelled by technologies that rely on sensors, big data, open data, new ways of connectivity and exchange of information (e.g., Internet of Things, RFID, and NFC) as well as abilities to infer and reason" (Gretzel et al. 2015, p. 1). Harrison et al. (2010) argue that smartness comprises the use of operational, real-time data, its integration and sharing, as well as leveraging optimization, analytics, and visualization techniques to facilitate operational decision making. Recently, the term "smart" has been connoted with a multitude of different concepts related to IT. The term has been added to the physical infrastructure, such as Smart Home, to increase technology integration blurring the lines between the digital and physical world. In connection with technologies, such as Smart Card or Smart TV, the focus is on multi-level functionality and efficient connectivity, whereas concepts such as Smart Economy foster new collaboration forms and value creation (Gretzel et al. 2015). However, many people have only a vague idea of what they consider smart in IT as different people associate different qualities and activities with the term (Gandhi and Robbins 2015). The term often follows a particular political agenda in order to sell specific technical solutions (Gretzel et al. 2015). Specifically, this is true for the Smart City case which promotes projects such as the Open Data initiative of the German government or endeavors for free Wi-Fi hotspots in German cities. Although these new attempts describe valuable new insights to collect, manage or share data, they lack in a full overview of the smart qualities and activities needed to enable Smart City applications or technologies. Further, a clear definition of smartness in general is missing which fosters the excessive and inconsiderate use of the term "smart" (Gandhi and Robbins 2015). Thus, the term is interpreted highly inconsistently and ambiguously across research.

3 Research Method

The goal of this research is to propose and evaluate a framework for SMAs, the Smart Mobile Application Framework (SMAF) by identifying their constituents and investigating how such a framework can be constructed by using smart activities and qualities. We follow a qualitative research approach using a single case study design. Single case study designs are only meant to be applied, if the comprised case is of critical, unique, revelatory, representative or longitudinal nature (Yin 2014). We selected the emerging concept of the "Smart City" for our case study, as the nascent concept stage and the sparseness of existing mobile solutions clearly bears its revelatory nature.

Case Study Context. The mobile application "City App" revealed a very good fit for our single case study, as it uses a substantial amount of different smart concepts (cf. Table 2) and relevant documentation for data collection exists. SAP SE acts as the provider of the City App and the backend system supporting it. In order to deliver the specific app, the city must present its particular requirements, so that SAP can customize the app appropriately for the particular city. In addition, third parties may develop extensions and specific content for the app.

Research Process. The research process comprises a literature review dedicated to the first research objective and the actual case study dedicated to the second research objective (cf. Figure 1). An inductive approach to explore the constituents of SMAs was required, as there is a lack of proper conceptualization. The literature review was used to overcome this shortcoming by developing new theory from existing work (Webster and Watson 2002).

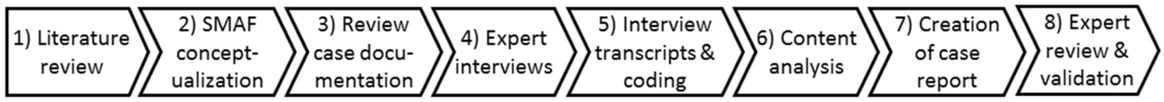

Figure 1: Simplified Illustration of the Review Process

In preparation of the data collection, a systematic literature review **(1)** was conducted to derive a theory-driven framework, guiding the data collection for our case study. Following the guidelines by Webster and Watson (2002) we have searched the leading journals and conferences by relying on the "WI-Journal list 2008" and the "WI List of Conferences, Proceedings and Lecture Notes 2008". To cover the mobile aspects of SMAs, the CORE Computer Science Journal and Conference Rankings were additionally considered. Databases such as ProQuest, ScienceDirect and EBSCOhost were used for the search (i.e. terms applied: "Mobile OR "Smart" OR "Intelligent" AND "App*"). Based on the literature review, we developed the SMAF **(2)** using two dimensions of smart software as a basis for the framework: smart activities and smart qualities. To acquire the relevant case data, two sources were used, i.e. documentation **(3)** and expert interviews **(4)**, which allowed for data triangulation to strengthen the construct validity (Yin 2014).

#	Role of Interviewee	Located	Medium	Duration (h:mm)
1	Project Manager	Germany	Face-to-Face	1:09
2	Software Architect	Germany	Face-to-Face	1:04
3	Software Architect	Germany	Face-to-Face	0:59
4	Researcher/Developer	Singapore	Telephone	0:57
5	Product Owner	Singapore	Telephone	1:01

Table 1: Overview Interview Sample

We used snowball sampling to identify the interview experts. The initial interviewee was the leading project manager (cf. Table 1), as he could provide a thorough overview of the subject and employees involved. The interviews were semi-structured, recorded and transcribed and we applied field notes during the interviews. A case study protocol and database were leveraged to store the collected data. We used a pre-defined set of codes from our literature review by deducing categories from the SMAF to code all interviews transcripts **(5)**. We applied the qualitative content analysis **(6)** approach as proposed by Gläser and Laudel (2013) to ensure that potentially new aspects discovered during data analysis could be considered at the category or variable level. NVivo was used to support our data analysis. Our case was supplemented with a case report including a qualitative case description **(7)**. We validated our results with four experts (two academic and two practitioners) **(8)**.

4 The Smart Mobile Application Framework (SMAF)

Due to the inconsiderate use of the term "smart", it remains unclear what the inherent qualities and activities of smartness are. Our review of existing definitions reveals that intelligence is a concept related to smartness. We observe applications of computational intelligence (CI) to derive characteristics of intelligent applications and cluster them within a framework along two dimensions (cf. Table 2): (1) the horizontal dimension is dedicated to the activities associated with smartness and (2) the vertical dimension comprises the smart qualities. Smart activities include "Sensing", "Decision Making" and "Learning" to illustrate how SMAs act intelligently (e.g. Poole et al. 1998; Russel and Norvig 2010), whereas the smart qualities show the abilities of SMAs of being social, proactive, reactive and acting autonomously (e.g. Woolridge and Jennings 1995). Given the lack of precision regarding the definition of smartness, the above mentioned activities and qualities are considered necessary for smart behavior, whereas additional qualities complement such behavior. We identified "Energy & Resource Management" as relevant smart quality.

	Sensing	**Decision Making**	**Learning**
Autonomy	• Physical Sensing • Virtual Sensing • Logical Sensing	• Personalization • Passive / Active Context Awareness	• Autonomous Learning • Semi-autonomous Learning
Social Ability	• App to User • App to Environment • App to Infrastructure	• Distributed Decision Making • Client/Server Task Sharing	• User Interaction Learning • Environment Learning
Proactivity	-	• Implicit Capabilities • Explicit Capabilities	-
Reactivity	-	• Specification-based • Learning-based	-
Energy Resource Mgt.	• Energy-aware Sensing • Distributed Storage	• Energy-aware Adaptations • Resource-aware Adaptations	-

Table 2: Smart Mobile Application Framework (SMAF)

4.1 Sensing

Autonomy. Autonomous sensing refers to acquisition of contextual information without direct user intervention (Woolridge and Jennings 1995). In general, three types can be distinguished (De Figueiredo et al. 2011): (1) physical, (2) virtual and (3) logical sensing. Physical sensors represent hardware sensors capable of capturing physical data. Virtual sensors capture data from software applications or services. Logical sensing combines data of multiple sensors (Lee et al. 2013).

Social Ability is interpreted as the capability to retrieve information provided from users or other systems in the sensing context (Woolridge and Jennings 1995). We identified that SMAs require a human interface as the interaction to users represents a key concern. The evolution of voice and gesture recognition, eye tracking and encephalography (EEG) further increases the level of user interaction (Geller 2012). Connectivity to the cloud, other devices, and stationary objects comprises a further key capability of the latest mobile devices. Cellular networks or Wireless Local Area Networks (WLAN) connect mobile devices with the internet and with each other (Nicholson and Noble 2008). Likewise, point-to-point communication technologies (e.g. Bluetooth) can establish communication between several devices, or stationary objects.

Energy & Resource Management is not a quality typically assigned to intelligent agents. However, SMAs are always used in the context of human-grade use cases. Without such quality certain use cases would not be feasible and hence not considered smart. For instance, sensing can be energy-intensive and saving strategies are needed: optimization of sensing intervals, compressed sensing, adaptive sampling, or pooling contextual information to share them among different apps on one device are popular applied strategies (e.g. Lane et al. 2014). Similarly, it can make sense to share sensor data between owners of different devices (Lee et al. 2013). Also logical sensing can be applied to save energy by using lower-power sensors as replacement for energy-intensive sensors if their capabilities are sufficient. Last, extending data storage to the cloud should be supported (Abolfazli et al. 2014), as storage is typically a scarce resource.

4.2 Decision Making

Autonomy. Barkhuus and Dey (2003) distinguish three types of interaction between users and applications with respect to decision making: First, personalization is dedicated to letting the user specify how an app should react in particular situations. Second, passive context awareness refers to presenting information to the user, whereupon the user can make an adaptation decision. Third, active context awareness is associated with autonomously changing “the application behavior according to the sensed information” (Barkhuus and Dey 2003, 2). There is a large debate about when to involve the user, as autonomous actions can induce users’ feelings of loss of control (Barkhuus and Dey 2003). In contrast, too much interaction can impair usability.

Social Ability. As mobile devices get more and more connected to other devices and infrastructures, there are techniques to distribute the processing of application tasks between mobile client and external entities, in order to improve decision making. Contrary, strong reliance on distributed resources increases the danger of low offline usability in case of lacking connectivity and fluctuating bandwidth (Abolfazli et al. 2014). Hence, applications should prepare for situations in which communication might be perturbed or interrupted, and adapt its behavior appropriately for instance by relying on partially cached data and thus increasing independence from remote processing and external data repositories (Abolfazli et al. 2014).

Reactivity is about using sensed data for particular application purposes. A prerequisite is to identify high-level situations properly by reasoning on low-level sensor data about the user’s environment, the current state of the device, and information about the user and nearby devices or objects (Ye et al. 2012). In general, one can distinguish specification-based and learning-based approaches: Specification-based approaches focus on creating situation models based on a priori expert knowledge and typically rely on logic programming, ontologies and reasoning engines. Learning-based approaches can be grouped into four categories (Ye et al. 2012): bayesian derivatives, information entropy, grammar and pattern mining. However, the nature of reactions on identified situations largely depends on the individual application and its purpose. One can distinguish three basic kinds of context-aware reactions (Dey and Abowd 2001, 5): (1) services and information presentation to a user, (2) automatic service execution and (3) context tagging.

Proactivity. In the context of decision making, proactivity can be understood at two different levels: (1) prediction and (2) the way of approaching the user. With respect to prediction, proactivity serves to identify future context and to leverage this knowledge for performing predictive actions (Boytsov and Zaslavsky 2011). Many of the aforementioned specification-based and learning-based techniques can also be applied for predicting context (Boytsov and Zaslavsky 2011). Proactivity is also concerned with deciding how and when to approach users. The most prominent techniques in this context comprise notifications and widgets. The disruptive nature of notifications can undermine users' capability of performing other tasks (Shirazi et al. 2014). There are two approaches to encounter these effects: (1) identifying situations, in which the user is not engaged in a task, or (2) deciding whether to approach the user based on the importance of the notification.

Energy & Resource Management. Computation offloading, i.e. remote processing by other devices offers opportunities for saving energy and boosting performance of decision making (Shi et al. 2012). In general, one can distinguish approaches, which seek to offload computation to a cloud infrastructure from those which try to outsource processing to other mobile devices (Shi et al. 2012). Not all actions within applications necessarily require high performance and immediate processing. Delay tolerant applications postpone processing, whenever immediate execution of tasks is avoidable by waiting for situations in which more energy efficient technologies can be used for data transmission (Wang et al. 2007).

4.3 Learning

Autonomy. One can distinguish supervised, unsupervised and reinforcement learning. Supervised learning approaches require a set of labelled data, such that a model can be trained for inferring or predicting the classes a data sample belongs to (Huai et al. 2014). Such classifiers are trained first by the developers and are then integrated into the app (Lane et al. 2014). Another approach involves applications trying to learn classifiers on their own (Cheng et al. 2013). Yet, such approaches suffer from the fact that applications may be able to distinguish certain patterns, but have to rely on users for labelling these patterns. Unsupervised learning does not rely on any observations and can thus be implemented autonomously, yet it "cannot explicitly reveal the semantic meanings of contexts" (Huai et al. 2014, 4), so that it cannot be applied effectively to context recognition. Reinforcement learning deals with "the problem faced by an agent that must learn behavior through trial-and-error interactions with a dynamic environment" (Kaelbling et al. 1996, 237). Thereby an application can observe the consequences from its actions and leverage this insight to improve its future actions.

Social Ability can also be applied to learn from user interaction or to improve other communication types. Learning about users' interaction with the application can significantly improve user experience and provides possibilities to adapt the application's behavior to the user. Likewise, applications can use information about connectivity to network infrastructures, e.g. by collecting information about the network connectivity at distinct locations, in order to forecast connectivity for traveling users to "more intelligently schedule network usage" (Nicholson and Noble 2008, 46).

5 City App Use Cases

Following, we describe the four main use cases which are currently supported by the City App:

(1) Entertainment. The app supports users with city "Events". Various phases of events with respect to user intentions are distinguished. In the discovery phase the City App supports the user to search for city events. A user in the decision enablement phase can review event information and bookmark events for later retrieval. In the confirmation phase the user acquires event tickets through the app. In the pre-event phase, the user will be reminded of the event, can make use of navigation and transport information, and check for free parking lots. The latter two actions are supported by an integration with the transportation and parking use cases presented below.

(2) City Infrastructure & Citizen Services. The app provides citizens with information about the municipal authorities' services and offers direct access to digital citizen services (e.g. filing requests to authorities). The "Safe City" features are dedicated to improve individual and community safety: users can send emergency notifications to the police and can enable other users to track them based on the device's GPS data. Further, they can request information about their current location or report unsafe zones. In turn, routing recommendations are given based on the safety indications reported by the community to avoid dangerous areas. With "Issue reporting" users can report issues such as contamination or road damages using the devices camera capabilities. A workflow engine at the authorities automatically triggers the required follow-up activities. The "Parking" use case focuses on exposing the real-time availability of parking lots and also predicting future availability.

(3) Local Commerce. For local commerce, "Deals" are offered to citizens and tourists. Payment is processed through third party gateways. In exchange for a payment, the user receives a coupon for the respective deal, e.g. in form of a QR code, which can be redeemed in local stores participating in the respective campaign.

(4) Multi-Modal Transportation is a feature recommending users the best way through the city based on their individual preferences. It considers both public and private transportation options. Consequently, not only transportation options offered by the city itself, but the use of taxis, car or bike sharing and similar modes of transportation are considered.

6 Smart Qualities of the City App

This section outlines the smart qualities applied in the City App context by discussing the SMAF along the activities "Sensing", "Decision Making" and "Learning". The overall results of our analysis are summarized in Table 3.

	Qualities	General Characteristics	City App Implementation
Sense	Autonomy	Virtual Sensing	*3rd party partner* & City App backend services
		Physical Sensing	GPS, Camera, Microphone
		Logical Sensing	*QR coding; Beacon technology; NFC*
	Social Ability	App-to-User	Graphical User Interface; Voice Recognition
		App-to-Environment	*QR coding, Beacon Technology, NFC*
		App-to-Infrastructure	Hana Cloud Platform (HCP)
	Energy & Resource	Energy-aware Sensing	None
		Distributed Storage	None
Decision Making	Autonomy	Personalization	Notifications
		Passive Context-Awareness	*Smart Privacy*
		Active Context-Awareness	Context-aware Content Adaptation
	Social Ability	Distributed Decision Making	Recommender Engine in backend
		Client/Server Task Sharing	Client/Cloud task sharing
	Proactivity	Implicit Capabilities	Prefetching
		Explicit Capabilities	Notifications; *Context-aware Widgets*
	Reactivity	Learning-based	Context-aware *& Social* Recommendations
		Specification-based	None
	Energy & Resource	Energy-aware Adaptation	Minimization of Network Requests
		Resource-aware Adaptation	Use of delay Tolerance Mechanisms
Learn	Autonomy	Autonomous Learning	User Behavior
		Semi-autonomous Learning	None
	Social Ability	User Interaction Learning	Use of User Interaction Data for App improvements
		Environmental Learning	None

Table 3: Overview of the Case Study Findings; Cursive activities represent future development plans

6.1 Sensing

Autonomy. The City App can make intensive use of virtual sensing by acquiring data from the City App backend and 3rd party partner backend systems. Physical sensors applied throughout City App use cases are primarily GPS, camera and microphone. Logical sensing can be performed in the context of location detection by making use of micro-location services such as QR coding, beacon technology and Near-Field Communication (NFC) for indoor positioning.

Social Ability. User interaction is restricted to navigation via a graphical user interface. An interviewed software architect points to a particular dilemma emerging in the world of mobile application development with respect to user interaction: "There are two trends: one trend is that mobile devices get bigger, and the other trend is that mobile devices get even smaller, that is wearables". Hence, it will be essential to provide more convenient input possibilities such as voice recognition for versions of the app dedicated to wearables. While the SAP Hana Cloud Platform (HCP) is used for hosting the backend components of the mobile app, there are technologies intended to establish communication between devices and stationary objects. QR coding and beacon technology is intended to provide information to users at distinct places while Near-Field Communication (NFC), on the other hand, is considered for making mobile payments.

Energy & Resource Management. The app does not yet make use of any particular energy saving strategies dedicated to physical sensing. However, the energy-drainage quest might not be so important for the City App, since the app aims at a relatively new generation of mobile phones and highly energy-draining activities such as continuous sensing are largely omitted at present.

6.2 Decision Making

Autonomy. The City App currently makes use of personalization and active context awareness. For instance, users can personalize app behavior by indicating whether they want to receive notifications. Autonomous adaptation of recommended information such as in the "Events" or "Deals" use case represents a type of active context-awareness. A type of passive context awareness might be introduced by the "Smart Privacy" functionality. Smart Privacy focuses on engaging the user into data collection decisions. A product owner refers to this mechanism as follows: "[…] the buzzword in this context is Smart Privacy, so that we collect only information, when it is transparent to the user, why we do this. […] you search for instance for concerts within a 5km radius and the user does this three times in a row. Then the app will prompt you after the third time: are you generally interested in this? Do you want more information (..)?".

Social Ability. The app makes comprehensive use of combining client and backend capabilities. A software architect provides an example for balancing backend and client capabilities: "We cache data in a local database and when you start searching, the results from the local database are shown. At the same time, a request is sent to the backend, and when the response is received, the results are fed in". Synchronizing cached and server-side provided information substantially increases responsiveness of the application, especially if network latency is high.

Proactivity. The mobile app makes use of both implicit and explicit proactivity techniques to support the user. A great part of the app functionality can be used relying on locally cached data, so that additional network requests are largely avoided. This kind of implicit capability entitled prefetching is primarily intended to reduce the number of requests made from the mobile client to the backend. Proactivity with regard to approaching the user (explicit capabilities) is a particularly sensitive issue in the City App context. While push notifications are applied, their use is very restricted, "[…] because we have recognized that notifications are not particularly desired. Most users turn off the recommendations, because there are too many of them". Thus, more emphasis is put on in-app proactivity by levering widget elements to inform users proactively when they actually interact with the app.

Reactivity. Apart from the plans to implement context-aware widgets, context-aware adaptation is predominantly performed in the "Deals" and "Events" use cases to sort lists of available deals or events based on user preferences, which are inferred by analyzing information about user behavior. Moreover, research is being conducted about extending the current recommendation functionality by also considering environmental context such as location and introducing group recommendations relevant to members of an entire social group. Currently, recommendations for deals are computed based on the combination of four techniques including popularity ranking, collaborative filtering, keyword pair association and purchasing pattern analysis.

Energy & Resource Management. One particular area in which the mobile app can exploit delay tolerance is maintenance tasks such as the transmission of logged usage analytics from the mobile client to the backend. In order to save battery life, mobile processors go to sleep mode if they are not required. Conducting maintenance tasks in one block reduces the number of processor and other peripherals wake ups. As most of today's mobile devices possess multicore processors, parallel execution of maintenance tasks can also save energy. Moreover, data acquisition is largely pull-based, i.e. network requests are predominantly upon explicit user interaction.

6.3 Learning

Autonomy. Currently, no semi-autonomous learning techniques are applied. Learning processes are performed autonomously by evaluating information from users' behavior in the backend.

Social Ability. A City App optimization to spatial fluctuations in network latency is currently not pursued as an increasing number of cities provides ample and free or low-cost access to wireless local area networks. Learning about user interaction is performed by transmitting user data to the backend, and evaluated by developers for improvements in navigation and content presentation

7 Discussion

While there have been attempts to define the term "smart" with respect to IT, it remained unclear what the inherent qualities and activities of smartness are. Our review of existing definitions in the context of computational devices revealed that intelligence seems to be a related concept to smartness. It is possible to observe applications of computational intelligence (CI) to get an idea of what characteristics an intelligent application should expose. Poole et al. (1998) define intelligent agents as systems that act intelligently by (also referred to as smart activities): learning from experience (Learning), and making appropriate choices given the systems limitations (Decision Making). Russel and Norvig (2010) further stress out the fact that intelligent agents should be capable of gathering useful information from the environment (Sensing). Woolridge and Jennings (1995) ascribe intelligent agents the abilities (also referred to as smart qualities) of being social, proactive, reactive and acting autonomously. However, whereas CI describes individual technologies such as deep learning or neural nets, SMAs take on more the outside view from a user's perspective. In that sense, an application might be considered as smart even if it is not using technologies typically classified as CI, but if they in turn comply with other smart qualities. Energy & Resource Management is such quality. Moreover SMAs put much more focus on the human-grade use case they support: e.g. SMAs require a human interface to interact with users, whereas the task performed by an intelligent agent might be a very fine-granular piece in a broader context with no human interaction. Thus, classic CI follows the weak notion of artificial intelligence (AI). The weak notion of AI is based on the notion of rational intelligence, which restrains the abilities of an intelligent agent to those that suffice to achieve "some defined performance measure given what it knows about its environment and about the effects of its own actions and about the current and past states of the system and the environment" (Poslad, 2009, 247). In contrast, we identified that SMAs represent a new class of intelligent apps following the strong notion of AI, which in addition to the weak notion, also replicates human behavior and is designed to enable the exhibition of emotional trades and higher human interaction levels (e.g. Woolridge and Jennings 1995).

The case analysis clearly revealed that there are *trade-offs* to be made: e.g. extensive use of different technologies is frequently associated with high energy consumption. Likewise, too strong reliance on backend capabilities might impair usability in situations, in which communication with the backend is not possible. Therefore, the implementation of a certain smart qualities requires investigating the effect it might have on important features of the application. Similarly, some smart qualities depend on the existence of other smart qualities (e.g. availability of a location sensor, if location is used as a context variable in the application). However, less obvious *dependencies* and interaction effects may unfold between smart qualities. Hence dependencies should be studied carefully. Ideally, every kind of smart quality, which is susceptible to failure, should be complemented with *countermeasures* to guarantee continuous application availability. The City App clearly outlined how offline capabilities complement social abilities to cope with network outages or bottlenecks, and to generally reduce backend reliance. This observation highlights the dependency of SMAs on environmental resources such as the availability of communication infrastructures. Therefore it is important to account for the locality in which the application will be applied. A further aspect that was uncovered is that SMAs can require different types of smart qualities throughout their *lifecycle*. Especially applications, which make extensive use of learning-based methods for providing certain functionality, can suffer from the lack of available data for interpretation, once the application is launched. To overcome the issue, external data can be used or a gradual transition from specification-based to learning-based models is applied. Last, the underlying *platform* of the app is an important aspect to be considered. The implementation of smart qualities can both support and impede the creation of native mobile applications, e.g. the current Android and iOS versions offer different capabilities regarding the detection of user locations. Likewise, the choice of the platform used for the backend can have great impact in realizing smart qualities.

8 Conclusion

This paper has conceptualized SMAs by describing their inherent qualities and activities. The analysis of the state of the art shows that most elaborations of smartness point to the concept of intelligence as fundament of smart behavior. However, SMAs represent a new class of intelligent application as they clearly focus on human-grade uses cases, whereas intelligent agents might represent a very fine-granular piece with no human interaction. In this line, we identified one additional quality of smartness in the context of mobile applications during our literature analysis and integrated it into the existing set. Based on these findings, the SMAF was derived, which aims to resolve the ambiguities surrounding the meaning of smartness. To address the SMAs implementation aspects, a case study dedicated to the mobile application entitled City App from the

Smart City domain was selected. The case study contributes to research by illustrating how the framework can be applied in practice and presents a first evidence of the appropriateness of the framework for analyzing real-world applications. From a practical perspective, the framework can be used for studying existing SMAs or serve as a tool for developing new SMAs. Likewise, the framework can benchmark own developments against rival applications. We are aware that our paper has some limitations. Any bias in the selected outlet and keywords may also provoke a bias in the conceptualization. Regarding the case study it is important to recognize that the generalizability of the findings is limited, as the analysis of smart capabilities at the example of a single application does not necessarily imply that the framework covers all requirements to be satisfied by other applications. We invite future research to (1) identify additional qualities and activities which might complement SMAs and (2) test our framework in different contexts.

9 Literature

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