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Information Systems in the Era of the Internet of Things: A Domain-Specific Modeling Language

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Abstract

Based on the technological developments of the last few years and the associated digitalisation, the Internet of Things is now an essential part of practically every aspect of life. Smart products with their sensors and actuators are not only boundary objects between the physical and digital world, but also tie both worlds more and more together. The capabilities of the products range from simple monitoring tasks by drones in agriculture to autonomous use in mining. However, in order to exploit the full potential of these capabilities, it is not enough to use individual smart products or sensors, it is necessary to develop holistic IoT-based information systems from the ground up. To take such a systemic perspective, it is essential to have a sound conceptual understanding of the domain and a common language. Against this background, the publication presents a domain-specific modelling language for IoT-based information systems.

1. Introduction

Digitalization has become increasingly prevalent, particularly due to the technological developments of the last few years. This has occurred in almost all areas of professional and everyday life, leading to an irreversible fusion of the real and digital worlds. At the heart of this development is the Internet of Things (IoT) and the associated smart products that serve a link between the real and digital world [17, 25]. Even system-relevant and formerly conservative domains such as agriculture, the energy sector, or even the health care system are subject to this disruptive transformation. For example, in health care, the use of IoT and intelligent products can help to reduce the costs of standard medical examinations in hospitals and specialized clinics. Particularly in the areas of health monitoring and ambient assisted living, the use of IoT-based systems has enabled completely new opportunities and possibilities [18]. For example, vital parameters such as blood pressure, pulse, or blood sugar levels can be measured and monitored remotely so that patients can be discharged more quickly after medical treatment or surgery [14].

The potential applications and the range of capabilities of IoT-based information systems (IS) are manifold, ranging from pure monitoring and remote control to being "capable of learning, dynamic adaptation, and decision making based upon data received, transmitted, and/or processed to improve its response to a future situation" [21]. McKinsey asserts that by 2023, 43 billion intelligent products will be used in the most diverse domains [12]. In the process of IoT becoming increasingly relevant, research has already intensively addressed technological and constructive challenges as well as strategic and procedural possibilities in the context of the use of IoT [5, 28, 32]. To be able to harness all of the potential, however, it is not sufficient to use individual sensors or smart products, but it is necessary to develop holistic IoT-based smart information systems. Nevertheless, to be able to adopt such a systemic perspective, it is essential to build upon a basic understanding of domain-specific terminology and a uniform language. In light of this, the following research question is examined:

How must a modeling language be designed to satisfy the demands of IoT-based information systems?

In the context of this publication, the research question is elaborated on the development of a domain-specific modelling language (DSML) after the approach of Frank [16] for smart, IoT-based information systems. The remainder of this paper is structured as follows. First, it elucidates the central topics of the Internet of Things and smart products and services. It then describes the DSML development process. Based on this, the developed modelling language is discussed in detail. The paper concludes by delineating the limitations of the work and suggestions for future research.

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2. Smart Products and Services

Based on technological developments in various areas, such as sensor or processor technology, and the associated increase in computing power and simultaneous miniaturization, the Internet of Things is changing not only individual products or services, but entire areas of life [13, 35]. The Internet of Things not only forms a bridge between the real and digital worlds, but also transforms existing physical objects into digital, intelligent objects [35]. Atzori et al. [5] describes this as "*a worldwide network of interconnected objects uniquely addressable, based on standard communication protocols*" [5]. In the context of the presented research, IoT and smart products are regarded as equivalent.

Smart products can thus be defined as advanced physical objects with sensory or acting components and a connectivity component, as well as an intelligent service offering based on these components [27]. The aim is to create significant added value compared to smart products' purely physical counterparts [22] by collecting data and interacting with the environment or other system-relevant objects. The smart products can operate independently of other information technology, or they can be integrated into information systems [20]. This is also reflected in the development of smart products, which has transitioned away from simple sensors (e.g., temperature, brightness, etc.) toward complex objects and independent system actors (e.g., Google Nest) [23, 25]. An essential component in this context is smart services, which have only become possible through smart products. These offer completely new capabilities, often specifically tailored to the user and extending far beyond existing digital services [2, 10, 19].

3. Research Approach

The presented paper is part of a multi-paper design science-oriented research project with the goal of developing an IS architecture for IoT-based information systems and a modeling language based on it that includes appropriate modelling tools. The presented research is an intermediate result, and it focuses on the development and evaluation of the domain-specific modeling language.

The goal of language development is to create a uniform discourse basis for increasing common understanding within research and practice, based on the translation of essential technological concepts into linguistic elements. This is intended to allow users to focus primarily on the use of the concept in the future, without being forced to reconstruct concepts on their own [16]. Domain-specific modelling languages have established themselves as a central methodological approach within the literature for this objective, as they include all constructs relevant to the domain and thus to the modeler in an appropriate, abstracted form. This makes it possible to create well-formed representations of the real world. This is not only reflected in the form of increased model quality; it also enables a better understanding of the model itself [9, 16].

According to Frank [16], the methodological basis of the three-step language development was the DSML development approach, which is established in the conceptual modelling literature. In the first step, the essential components of the language, their dependencies, and the corresponding modeling rules were defined as abstract syntax in the form of a meta-model [9]. The meta-model development is based on two independently conducted and published preliminary studies within the domains of smart agriculture [29] and smart health [30]. In each study, a domain-specific information system architecture was developed based on an exploratory literature analysis of more than 6500 publications (6024 Health / 547 Agriculture) and the aggregation of more than 90 domain-specific architecture approaches (55 Health / 37 Agriculture), according to Webster and Watson [34] in combination with Vom Brocke et al. [33]. Starting from the two domain-specific information system architectures, the essential concepts were inductively extracted, abstracted from domain specifics, and aggregated in a domain-independent meta-model.

Based on this, in a second step, the abstract concepts of the meta-model were concretized, textually defined, and transferred into a concrete syntax in the form of a graphical and textually descriptive notation. The objective of the transformation step is the operationalization and utilization of the abstract concepts [16].

In addition to the development of the language, its evaluation and the demonstration of its usability is an essential part of language development [16]. For this reason, in a final step, the developed DSML will be applied to a real-world smart health scenario – nCapp, an IoT-based COVID-19 Intelligent Diagnosis and Treatment Assistant Program [6]. The result of the development process is the Smart Information System Modelling Language (SISML), a domain-specific language with which it is possible to model information systems, digital platforms, or entire ecosystems based on smart products and services.

4. SISML – A DSML for IoT-based Information Systems

4.1 Abstract Syntax

The starting point of the SISML was the aggregation of domain-specific information system architectures, while abstracting from domain-relevant concepts to adopt an independent, systemic perspective of IoT-based IS. Four essential artifacts have emerged, independent of domain or use case: smart product, smart service, network, and data. Smart products are an integral part of the model.

They consist of three basic components: a sensory or an actuatorial component, a connectivity, which enables the products to exchange data with other smart products or other system-relevant entities, and a physical one, which encloses all of the components [27]. Within larger system landscapes with a large number of individual intelligent products or dedicated sensors, such as those commonly used in agriculture [1], these act as nodes or sensor nodes in wireless sensor networks [36].

Another essential artifact within any information system and thus also within the meta-model is the data generated or processed by the system and its components. In the context of IoT-based systems, this data can be classified into smart, corporate, and external data. Smart data includes all data generated or measured by smart products and their sensors; this may be data about the product itself, its environment, or the interactions between a product and another system's entities [25, 26]. Furthermore, the system also contains corporate data relevant to system operation, such as master data or payment data and external data not generated by system entities. This further enhances existing data by incorporating information not available to the company (e.g., weather data).

In order for the individual entities of the system to be able to communicate with each other, most IoT domains (e.g., smart home, smart farming) use two categories of network topologies: short-range and long-range [3]. Within some domains, these classifications are further specialized. For example, in the smart health domain, so-called wireless body area networks are used. These connect sensors and actuators that are placed very close to the body over a certain period of time or even permanently, or in some cases firmly implanted in the body [7]. Based on the principle of abstraction and domain-specific literature [7], these can be subsumed under two main categories. "Short-range" refers to the use of technologies such as Wi-Fi, Bluetooth, ZigBee, or RFID, which cover a range of several centimeters up to about 100 meters [8]. Long-range protocols, which are used in the field and are based on existing infrastructure such as 5G or use the help of low-power wide-area networks (LPWAN) specifically set up for the application, can cover distances of several kilometers [3]. However, for most of the application cases under consideration, a hybrid use of the different network topologies is appropriate.

Smart services represent borderline objects between service users and service providers [10]. They are therefore the contact point as well as the central interaction opportunity for the system user. Within many domains in which smart products and services are used (e.g., smart homes, smart entertainment, etc.), the corresponding services are primarily consumed by end users. In contrast to this, however, there are also fields (e.g. smart health) in which there is a strong shift toward trained specialists and domain experts as end users, which allows a significantly broader spectrum of users and, correspondingly, a wider range of requirements. Regardless of the type of user, every service should offer added value (value proposition) for the user [10] and lead to the desired result (main outcome) [11]. The value proposition of the service can be functional, hedonic, or social, whereas the main outcome of the service offering can be characterized as efficiency gains, added value, or new offering [24].

To be able to use the corresponding service offers and benefit from the respective added value, the user has three different means of consumption at their disposal. Paukstadt et al. [24] define these as the main interface and classify them into three categories: device-based (use of smartphones, tablets, web browsers, etc.), product-based (use of the interface of the smart product), and human-based (interaction with a domain specialist) [24].

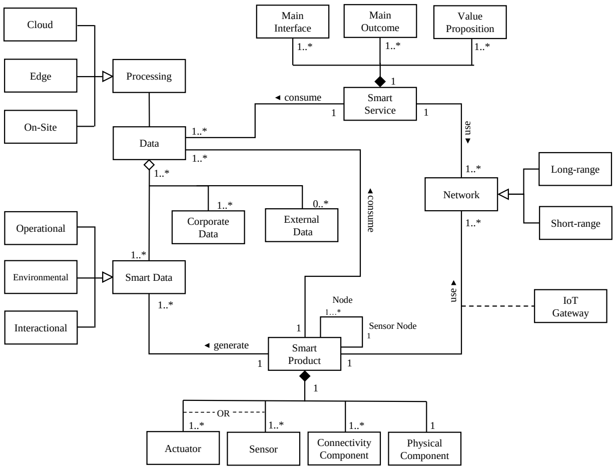

Figure 1. Meta-model

4.2 Concrete Syntax

The concrete syntax of the SISML consists of both graphical and textual notations (Figure 2), which were developed based on established visualization guidelines [4]. The basic elements of the language are smart products and services, which, based on product or service characteristics, are enriched with annotations containing further information. The element class of smart products is not only represented by smart products themselves; it also includes the potential to model dedicated sensors or actuators without smartness capability.

Depending on their characteristics, the products can be enriched with up to three sensors and actuators with up to two property categories (processing, network, data). The properties within the categories are not to be considered exclusive. Thus, it certainly makes sense for a smart product to collect operational and environmental data simultaneously, whereas it is rather unlikely that the product will communicate simultaneously over a short- and long-range network connection. These syntactical possibilities offer the modeler a certain degree of freedom, but also require a corresponding degree of care.

Smart services adhere to essentially the same structure as smart products, but they are represented by the geometric shape of the triangle. The focus of the modeling is on the service properties (main outcome, main interface, value proposition). Here, too, the properties do not have to be mutually exclusive, so that a smart service can simultaneously offer the user

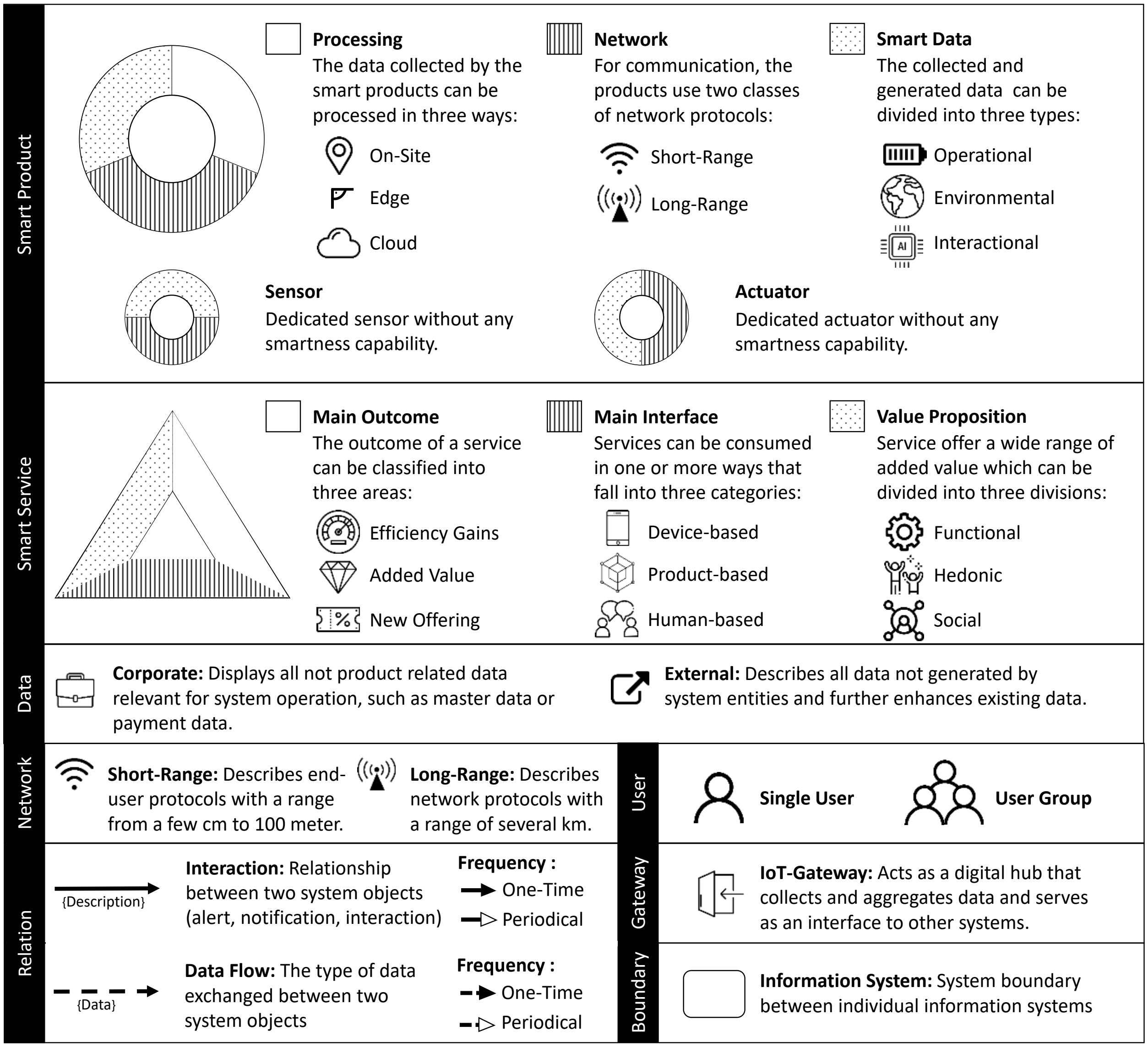

Figure 2. Concrete syntax

both functional and hedonic added value. A classic example is smart fitness trackers, which enable the user to monitor their caloric consumption (functional) and at the same time support them in reaching their fitness goal (hedonic).

In addition to the basic modeling of smart products and services, the syntax focuses primarily on their relationships and interactions. These relationships can be represented with the relations on the data level as well as on the interactional level (etc. alert, notification, use) both once and periodically.

The differentiated data types make it possible to model not only abstract data flows, but also to specify explicitly which data is generated or exchanged, thus increasing the model's quality. In the context of the syntactical development, it was also ensured not to concretize the user, but to offer freedom to the modeler to express this with domain-specific roles.

5. Evaluation and Demonstration

The modelled scenario describes nCapp, an IoT-based health platform for intelligent diagnosis and treatment for COVID-19 [6]. The following scenario describes two classic applications of the platform from both, the patient and the physician perspective (Figure 3).

Tom has been feeling weakened for a few days and has elevated temperature. However, in order not to endanger himself or his fellow people in the current global situation, he decides not to go to the doctor physically, but to have himself diagnosed via nCapp. To do this, Tom transmits disease-specific vital signs, such as temperature, heart rate and blood oxygen, which he has measured by using his Apple Watch and an application-compatible thermometer, to the nCapp App (1). In addition, he further enriches the vital data with information not measurable by the devices, such as his weakness or pain sensation, by using the smartphone app (2). The collected vital data and the answered disease-specific questionnaire are transferred to the nCapp data center for evaluation (3). After the analysis of the data, Tom receives an individual treatment plan and a classification of his disease state with further instructions (4).

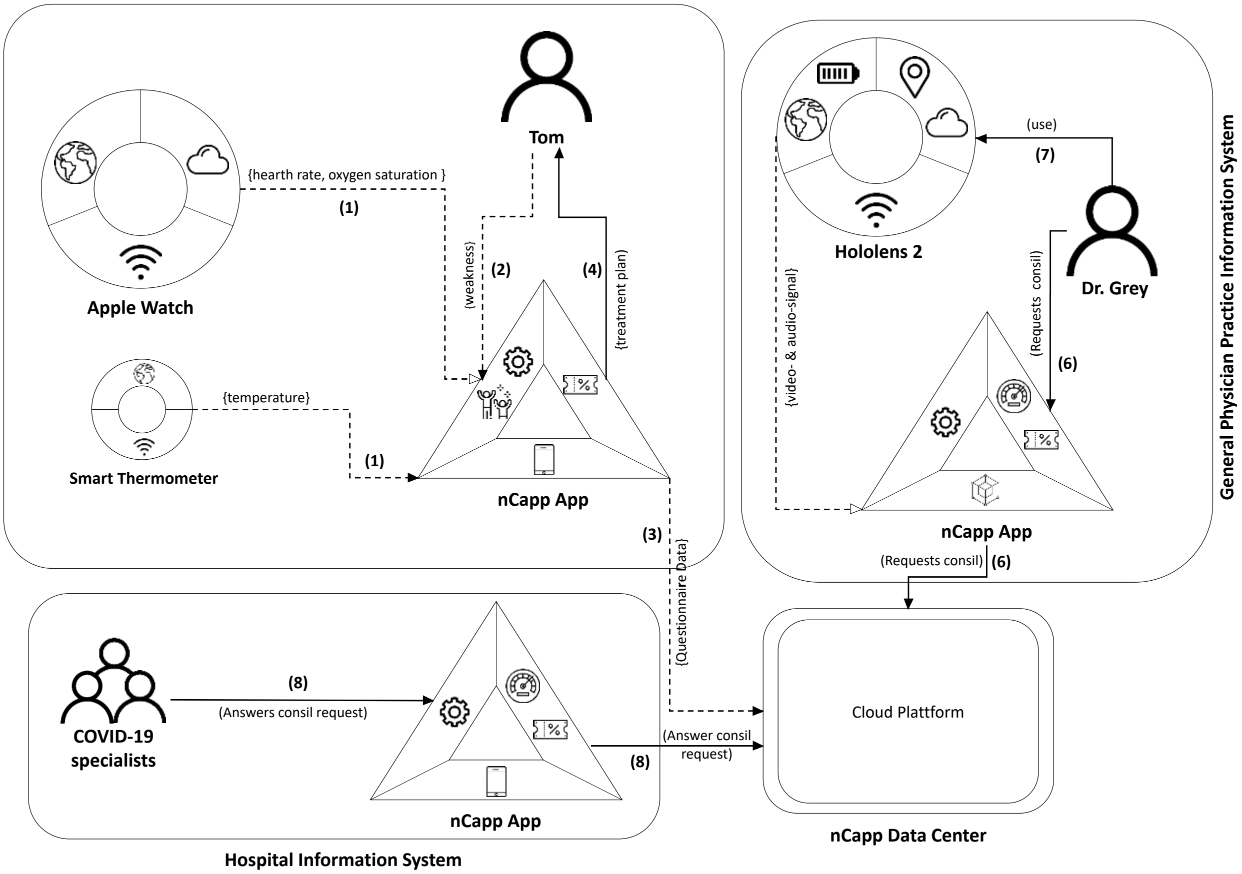

Figure 3. Evaluation - ncapp

In addition to patients, the nCapp app is also intended for the exchange between doctors. Dr. Grey, who is a general physician, is today during her consultation hours for the first time in contact with a patient suspected of having COVID-19 and a moderate respiratory disease. Since she has little experience with the course of the disease and does not want to carelessly activate local intensive care resources, she is asking for a consultation with experienced colleagues (6).

In order to offer her colleagues, the possibility of an independent anamnesis and to be able to interact with them and the patient at the same time, she uses a Hololens 2 for image and sound transfer (7). Dr. Grey's consultation request is submitted to the corresponding specialists using the nCapp-App and is accepted by an available expert (8). This expert then joins in during the examination by means of a simple video chat or equivalent augmented reality glasses.

6. Conclusion and Future Outlook

The use and integration of smart products will increase in the coming years as digitalization progresses. McKinsey predicts that by 2023 more than 43 billion intelligent devices will be in use in various domains of everyday life, such as smart homes, smart energy, smart cities, or smart health [12]. For this reason, it is essential for modelers and system developers, especially in system-critical areas such as healthcare or the energy sector, not only to have a basic and independent but also common understanding of intelligent products, their structure, interaction possibilities, and range of services. This can enable them to participate in the development of new smart information systems or in the transformation process of existing systems.

Against this background, this paper offers a systematic and methodologically sound artifact for the analysis, development, and modeling of information systems in the form of a domain-specific modeling language for IoT-based information systems. The SISML can serve both as a tool for the analysis of existing information systems and as a conceptual tool for the development of new systems. The central focus is not only on the system-relevant components but also on their relationship to each other. Although the research presented provides both theoretical and practical implications, it is not free from limitations. Especially in the context of a constantly changing and technologically evolving object of observation, such as the Internet of Things, the presented DSML and its concepts can only provide a snapshot of the current state of development. For this reason, it is essential in the context of future developments to further evaluate the language and its elements and, if necessary, to adapt it to future changes as well as future possibilities.

Thus, the presented modelling language offers researchers a methodologically sound starting point for the development and modelling of dedicated IoT-solutions and a contact point for future research. The central focus should be primarily on the development of an independent modelling tool for the presented DSML, with which researchers and companies can productively use language without immense effort. Existing meta-modelling tools such as MEMOCenter [15] or MetaEdit+ [31] could serve as a starting point for development. A further technological aspect that could be explored in the context of the development of a corresponding modeling tool would be the porting of the tool from the second to the third dimension by using augmented reality. By enriching reality with data relevant for modeling or system analysis, new possibilities and added value could arise for both the modeler and the model user. In the next step, based on the results of this paper, a first prototypical implementation of the language for the Microsoft Hololens 2 is going to be developed. Finally, the developed language offers new opportunities related to the development and modelling of IoT-based information systems and creates a conceptual basis for future research within the field.

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