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Digital Object Memories in the Internet of Things

Michael Schneider, Alexander Kröner, Patrick Gebhard, and Boris Brandherm

Digital Object Memories, DOM, comprise concepts and technologies to physically and conceptually associate digital information with physical objects in an application-independent manner. By storing information about an object's properties, state, and history of use in its digital memory, objects become self-representative, which allows for novel kinds of open-loop applications in the Internet of Things. In this paper we report on work performed on architectures for Digital Object Memories, concepts for interacting with Digital Object Memories, and the application of Digital Object Memories in the context of the Internet of Things.

Keywords: Digital Object Memories, Internet of Things, Semantic Product Memories, Semantic Web.

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1 Introduction

Digital Object Memories, DOM, comprise hardware and software components that physically and/or conceptually associate digital information with real-world objects in an application-independent manner. Such information can take many different forms (structured data and documents, pictures, audio/video streams, etc.) and originate from a variety of sources (automated processes, sensors in the environment, users, etc.). If constantly updated, Digital Object Memories provide a meaningful record of an object's history and use over time.

From a *technical point of view*, Digital Object Memories provide an open-loop infrastructure for the exchange of object-related information across application and environment boundaries. Besides fostering information re-use and reducing the risk of information inconsistencies, they allow for novel classes of applications in which rich object histories are created and exploited. From the *user's point of view*, Digital Object Memories create a new design space for everyday interactions. Physical objects could become sites for their owner's personal stories, but also afford people the opportunity to explore an object's provenance and connections to other elements of physical and digital life. In this sense there is the potential for designers to augment or even transform our relationship with objects and the services that they mediate.

The concept of Digital Object Memories on the one hand and the idea of the Internet of Things on the other hand complement each other perfectly. As a collection of general object-related information Digital Object Memories make physical items self-representative and hence provide a valuable knowledge source that can be exploited by applica-

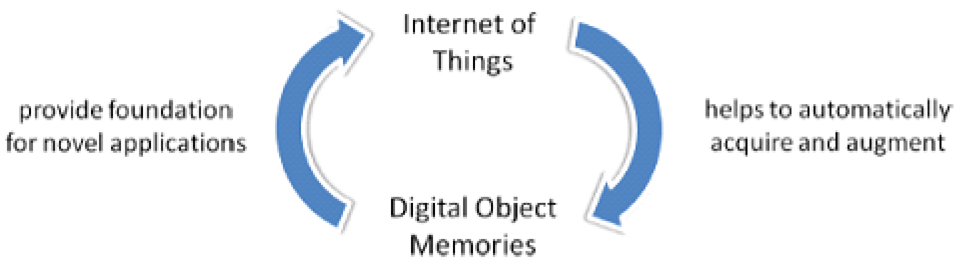

Figure 1: Relation between Digital Object Memories and the Internet of Things.

> "Digital Object Memories provide a meaningful record of an object's history and use over time"

tions in the Internet of Things to realize novel kinds of context-adaptive services. In parallel, the Internet of Things approach allows for the continuous updating and augmentation of an object's digital memory. Sensors installed in the environment or attached to other objects can assess an object's current state and context. This can also take place for applications that involve a particular object, which can gather information about the object's role and usage in the current application context and store this information in the object's memory. Figure 1 illustrates the close relation between Digital Object Memories and the Internet of Things.

In this article we report on work that we performed over the last year on different aspects of Digital Object Memories and the Internet of Things in the context of the research project 'Semantic Product Memories', SemProM. The rest of this article is structured as follows:

First we review other work that is related to the general idea of Digital Object Memories.

Next we present a layered architecture for Digital Object Memories that takes into account different technical limitations that may result from varying degrees of instrumentation applied to smart objects in the Internet of Things.

Then we present an evaluation scenario that we implemented in the context of smart shopping assistance. Within this scenario we demonstrate different applications of Digital Object Memories and present results of a user study that was conducted in this scenario.

We give a short overview about the topics and organization of the underlying project SemProM and finally conclude this article.

2 Related Work

The idea of equipping physical objects with 'personal' memories is a natural consequence of Mark Weiser's initial vision of ubiquitous computing; even more after Bruce Sterling recently popularized the idea of smart objects and the so-called "Internet of Things". Sterling coined the term *spime* [1] to describe a new category of space-time objects that are aware of their surroundings and can memorize real-world events. Julian Bleecker advocated a similar notion of blogjects (objects that blog) in his "Manifesto for Networked Objects" [2]. This more visionary work has been met by a growing body of technology - and business -focused research on RFID, smart objects, and smart products [3].

Electronic pedigree [4], for instance, aims at protecting consumers from contaminated medicine or counterfeit drugs. It establishes a link between a physical item and external data sources which enables a verification of the physical item's integrity along several steps of such products' lifecycle. Furthermore, according to Decker et al. [5], the use of smart labels for object-based tracking and quality monitoring may be beneficial for the business partners along the supply chain.

Regarding the infrastructure for such applications with various business partners and user groups, Schmitt et al. [6] emphasize the value of open structures for data collection and exchange. This is also reflected by the approach of Schneider [7], who proposes a Web-based Object Memory which serves as an open reference to object-related information hosted and controlled by arbitrary content providers.

Other work is related to the issue of modelling data for object memories. For instance, with the increasing distribution of smart labels in mind, Maass and Filler [8] suggest the linking of physical product items with digital information in order to support customer-oriented services such as a product comparison. They rely on facets (e.g., "business", "security") to encode domain-dependent views on a product - which is different from the abstraction-based model we use in our system. Decker et al. [9] even propose a further application of an information link for physical items: By storing parts of the business logic in a smart label with its own sensing and processing capabilities, a physical item can be enabled to participate actively in the monitoring of the underlying business process - an approach we consider complementary to the process view on item-based information discussed in this article.

3 General Architecture for Digital Object Memories

In this section we present a layered architecture for the hardware-independent realization of Digital Object Memory functionality through smart objects with varying degrees of instrumentation. Such heterogeneity of applied technological platforms is often given due to constraints that might be posed for technical, social, or economic reasons. In order to act as a general and application-independent approach, a unified architecture for Digital Object Memories has to account for these differences, thus making the idea of Digital Object Memories applicable to a huge variety of different platforms with varying capabilities. In particular, deficits immanent to weakly instrumented smart objects like low CPU power or short memory can be compensated for by delegating memory functions to other objects or a more powerful environment.

> "Electronic pedigree, for instance, aims at protecting consumers from contaminated medicine or counterfeit drugs"

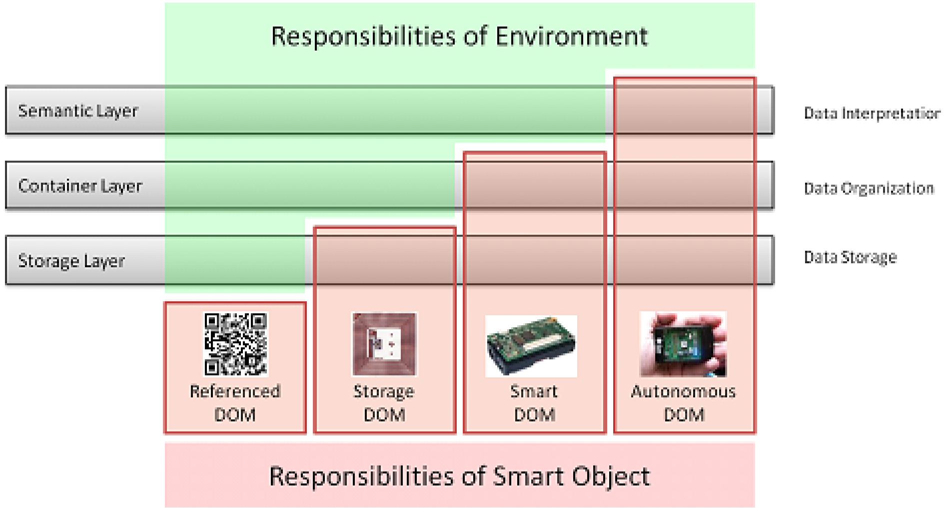

Figure 2: Layered Memory Architecture and Resulting Sharing of Responsibilities between Smart Object and Environment for Basic Memory Classes.

The layered memory architecture that we present in the following allows for the identification of the separation point of split responsibilities between the smart object and its surroundings. We propose to distinguish three layers of memory functionality that build on one another to realize the overall Digital Object Memory service (see Figure 2):

1. **Storage Layer**: The storage layer is responsible for the physical data storage. It holds the bits and bytes that form the memory content, but it does not know anything about the structure, organization, or meaning of the contained data. The interface to the storage layer, for instance, allows it to ask for the first 10 kilobytes of raw memory content.

2. **Container Layer**: The container layer provides a structured view of the information contained in the storage layer. It allows identification of individual memory content items and provides information about their type and other metadata. However, it does not know how to interpret and understand the data. The interface to the container layer for instance allows requests for all images that have been stored in the last 14 weeks in the memory.

3. **Semantic Layer**: The semantic layer allows for the abstract interpretation of the information contained in the memory. This involves understanding the data format of the information and may even include reasoning about larger sets of memory items. The interface to the semantic layer for instance might allow requests for the average temperature of a food item over the last week.

Depending on the degree of autonomy of the smart object (and the resulting set of responsibilities it can take) we distinguish four basic classes of Digital Object Memories (cf. Figure 2):

- **Referenced DOM**: In its simplest form the object's instrumentation is just some kind of read-only storage which provides a reference to a memory service that is completely hosted by the environment. The read-only storage can take many forms, ranging from simple optical markers over passive RFID transponders to active components which allow queries to the infrastructure-based object memory service. In this setup the object needs to provide little, or no, resources in order to provide DOM functionality as all relevant work is performed by the environment.

Figure 3: In the evaluation scenario the user creates a shopping list (1), transfers it to a smart shopping cart via her DOM-based car key (2), inspects a product's history (3), and uses a fast and hassle-free self-checkout (4).

"Depending on the degree of autonomy of the smart object we distinguish four basic classes of Digital Object Memories"

■ **Storage DOM**: Through its instrumentation the object might be able to store a limited amount of digital information on its own. However, due to the application of passive technologies like passive RFID transponders, or due to constraint processing power, the object might not be able to actively manage and interpret memory content. Hence, memory access, memory organization, and interpretation of memory content have to be performed by the environment.

■ **Smart DOM**: If active components with sufficient processing power are available as part of the object's instrumentation they may be used to implement container layer functionality on the object itself. This means, that other objects and the environment can use a more powerful interface to selectively query particular information items from the object memory instead of simply 'downloading' the complete memory content. Evaluation and processing memory content still have to be performed by more powerful components in the environment.

■ **Autonomous DOM**: If the smart object is equipped with powerful computing capabilities it might be able to autonomously answer queries that require a deeper understanding of the memory data semantics. In this case, the environment can directly read the desired information from the object's digital memory. For the environment this is the most efficient and specific way to query an object memory, but it also poses the biggest challenge regarding the smart object's instrumentation.

Implementations of Digital Object Memories may apply to more than one of the above at a time. A hybrid memory structure based on a passive RFID transponder, for instance, may use referenced storage to store large amounts of information that is available through a high-bandwidth connection, and at the same time may act as a "storage DOM" by using remaining parts of its transponder storage space as a local cache that is accessible even without the presence of a communication link to the referenced remote storage system.

More complex memory structures may be composed of multiple DOMs. An "autonomous" DOM for instance may utilize several other "smart DOMs" or "storage DOMs" in its vicinity to swap memory content. This of course requires that the autonomous DOM has the according capabilities to communicate with the other DOMs, e.g. by means of embedded RFID readers. The proposed general architecture for Digital Object Memories even allows for multi-level memory structures, in which higher-level memories act as a kind of proxies for lower-level memories. E.g., a complex machine comprised of several subparts with own DOMs can appear to its environment as a single entity with a single memory, where the assembled machine's memory is just a proxy for the individual parts' memories.

The general object memory architecture presented above provides the foundation for the implementation of the evaluation scenario that we present in the following.

4 Evaluation Scenario "Intelligent Shopping Assistance"

Next we describe an evaluation and demonstration scenario that we set up to test the practical feasibility of the developed technical concepts and implementations, to demonstrate possible use cases for Digital Object Memories, to show the resulting added-value, and to evaluate the user acceptance of DOM-based technologies and services. Furthermore, the scenario shows how objects and their memories may play different roles during the interaction with an environment and the provided applications.

4.1 Scenario Description

The chosen evaluation scenario considers multiple stages of a private user's shopping tour. During this tour, the user interacts with different objects and object memories. Data from these memories hereby is used to provide different kinds of novel support services to the user and store. In the context of this article we cover four stages of the shopping tour as shown in Figure 3.

4.1.1 Preparation at Home

The scenario starts with the user being at home and preparing her shopping trip. Here, the user can exploit information from previously bought products, respectively their memories, to create a shopping list for an upcoming shopping tour. A large-scale touch screen allows the user to communicate with an embodied Virtual Character that guides the creation of the shopping list (see Figure 3, Stage 1). It has a large repertoire of conversational gestures and is able to generate all needed utterances by using a template-based character control and text generation system together with an actual TTS system (Nuance). The character is aware of all products at home and their status, which can be a) available, b) need to buy, c) need to buy soon. In addition, the character suggests recipes, whose ingredients can be transferred to the shopping list.

"The chosen evaluation scenario considers multiple stages of a private user's shopping tour"

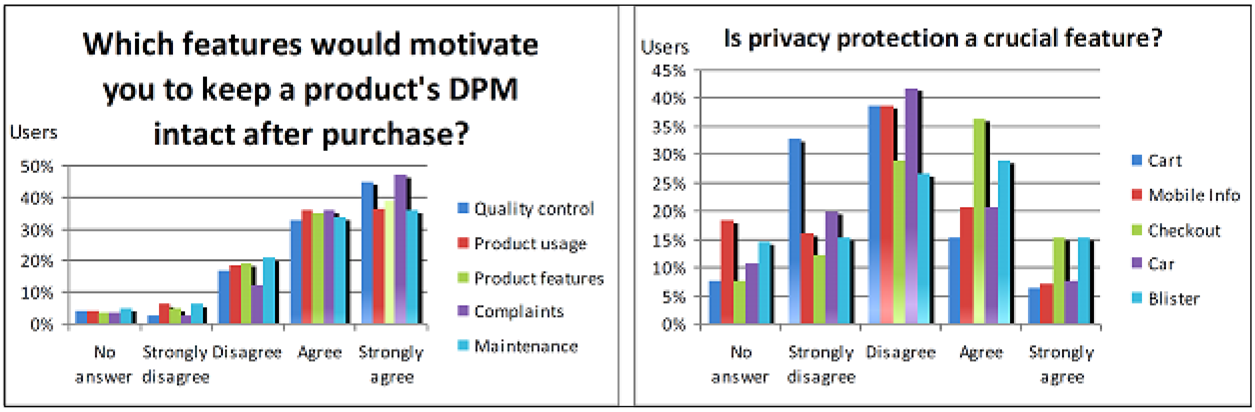

Figure 4: Visitors' Feedback. Would they keep the DPM intact, where is privacy protection (especially) crucial?

Once the user is satisfied with the list, it is transferred to the Digital Object Memory of a "Personal Token" — a personal item the user owns and trusts. In our scenario, this is the user's car key that is equipped with a NFC chip [10]. In the associated Digital Object Memory the key holds a shopping list, together with other general data like credit card information or a personal profile. The latter consists of favourite products, allergy information, and individual nutrition aspects. The Personal Token is supposed to be taken to public spaces where it can be used to reveal — at will — a small set of personal data in order to obtain personalized support.

4.1.2 Finding and Choosing Products

At the entrance to the store, the user takes a shopping cart which is equipped with multiple RFID readers in the handle and basket, a touch-screen display, and a wireless communication and processing unit. Once the user places the key at the cart handle, the shopping cart system retrieves the shopping list and the personality profile from the Personal Token's DOM to enable a guided shopping tour (see Figure 3, Stage 2). Shelves and a refrigerated display case represent the public infrastructure and are also equipped with RFID antennas and displays. Shelves and refrigerated display case are aware of the position and amount of locally stored goods, and have access to the goods' Digital Object Memories to retrieve product information from them. The digital memory of goods is realized as a referenced DOM based on passive UHF transponders.

A virtual character on the cart display guides the user through the shopping list and recommends products matching her shopping list and user profile. It resembles a personal advisor that checks every product that is placed in the cart with respect to individual needs and interests. The underlying service exploits content of the respective DOMs to make decisions regarding conflicts with the personality profile. Emerging conflicts are addressed via natural language by the cart character, while additional information is presented on the cart's display.

In addition, the character on the user's cart may ask "expert" characters shown at displays mounted on shelves for more detailed information, e.g., if there is a product alternative. These shelf characters resemble salespersons. E.g., they provide help by giving in-shelf navigation hints that help the user to find needed products. In addition, the characters communicate general product-related information like price, producer, etc. in a natural conversational style. By utilizing knowledge retrieved from the DOMs of the involved products the virtual characters can react intelligently to the consumer's interactions with the available products.

4.1.3 Exploring Products

An information kiosk in the store enables the customer to explore the nature and history of a concrete product instance more deeply. If the user places a product on the RFID-enabled board of the kiosk, a "product diary" is presented in form of a temporal sequence of product-related events. Such events range from production information over logistics data up to information used for product display at the retailer (see Figure 3, Stage 3). In addition, information about the current and past state of the product, e.g. about the temperature of frozen food, is stored in the memory. While production and product data was pre-generated and fixed for the purpose of this particular demo, information like temperate-related events could be generated on-site, thus allowing the user to experience the idea of quality control via DOMs.

4.1.4 Buying Products

At the end, the user leaves the store with the cart or basket through a self-checkout gate (see Figure 3, Stage 4). Via the use of RFID and information from the DOMs, the checkout counter automatically identifies the content of the cart or basket. At the same time, the payment is authorized via the credit card information in the Personal Token's DOM. A screen at the gate displays all products recognized; if the user actively places the card key at a specific location nearby, payment is authorized and the DOM of each detected product is updated with the information that it is now owned by the customer. In addition, time and location (store) are stored, e.g. to ease a later claim of warranty rights.

> “The shopping scenario was presented at the CeBIT 2010 fair and drew considerable attention”

4.2 Evaluation

The scenario described above was presented at the CeBIT 2010 fair and drew considerable attention. Accompanied by expert "demonstration pilots" visitors followed the stages described above and were allowed to interact personally with the different applications. Each stage provided the visitor with some degree of freedom (e.g., concerning the products to add to the shopping list and to the shopping cart). Visitors who made a full "shopping tour" typically spent up to 40 minutes at the exhibit. Some of these visitors were asked to answer a few questions afterwards. These questions addressed three major topics: user interface, usefulness of service, and potential privacy issues. These were reflected by three hypotheses that we made in advance:

H1. Direct or indirect interaction with objects is an appropriate opportunity to trigger shopping support.

H2. People would like to use a DOM beyond the basic shopping process.

H3. Trusted security mechanisms increase trust in the DOM to an extent that justifies storing personal data at the item.

The actual questionnaires addressed:

- Demographic data and purpose of the visit
- Knowledge about RFID and similar technologies
- Preferences regarding interaction device and modality
- Utility of car-related services and factors affecting a buying decision
- Conditions motivating a user to keep a product’s DOM intact after purchase
- Trust in the protection of personal data, and rating of privacy at the different demo stages
- Effects of the application context

For most of these questions, potential answers were arranged on a four point Likert scale. Filling out the questionnaire took a further 10-20 minutes. A project member guided the visitors through the questionnaire and provided additional explanations if needed.

4.2.1 Participants

132 participants took part in the evaluation, 71% male and 24% female. 65% of them were less than 30 years old, a further 23% were between 31 and 50 years old. Thus, the answers might be biased towards the perspective of male participants. The reason of the CeBIT 2010 visit was, in most of the cases, a private one (66%).The participants experience with RFID was surprisingly low (for an IT fair) - 50% of the answers expressed little or very little experience with this technology, opposed by 41% with (strong) experience.

4.2.2 User Interface

The demonstrator intentionally mixed a wide range of different interaction types. These involved specific mechanisms such as a smart shelf as well as general purpose access mechanisms, such as the user’s mobile phone. 84.85% of the answerers expressed a preference towards the latter approach.

The interaction relied on involved implicit mechanisms (e.g., product detection during checkout) and on explicit ones (e.g., exploration at the kiosk). Employed modalities included point & click (touch, pen), tangible interfaces, and speech (output only). Participants were asked for their favoured interaction type. The majority of answers (73%) addressed graphical user interfaces, followed by tangible ones (16%) and speech-based ones (11%). Participants were allowed to express multiple preferences.

To some extent, both results support H1. However, they also express a preference towards traditional interaction types where the user actively evokes some service via a multi-purpose device he or she already owns.

4.2.3 Privacy and Trust

For applications of the DOM beyond the shopping process, e.g., quality control in a smart kitchen environment, it is crucial that the DOM hardware of a product stays intact after payment. 77% of the answers indicated a will to keep the DOM in place for quality control, information concerning product application, information concerning product features, and/or issuing complaints concerning the product (multiple choices possible, see Figure 4, left-hand side). This supports H2; however, differences in the feedback to the various services also indicate that the application of H2 should be judged with respect to the kind of product.

The DOM and related technologies can be exploited to collect and transport data regarding a user. While the participants’ trust in the protection of their data in general was limited (32% positive, 63% negative answers), the means of privacy protection employed for the medicine blister were perceived more positively (40% positive, 50% negative answers). Thus, while the latter result supports H3, the installed mechanisms alone are apparently not sufficient to resolve trust issues in general.

The need for data protection was perceived differently for the individual elements of the scenario. It was rated as crucial for checkout and possible follow-up home applica-

> “The deployment of digital product memory creates significant added value along the entire product value chain”

tions (see Figure 4, right-hand side). This indicates a special need for data protection if a DOM is applied in a public space to retrieve or communicate personal data, and if the DOM of a personal product is employed for collecting data about its application. Interestingly, a business or private application of a DOM might affect these interpretations only to a small extent, since 71% of the participants would not see a difference there.

5 About the SemProM Project

Within the IKT-2020 research program of the German Federal Ministry of Education and Research the Innovation Alliance 'Digital Product Memory' is developing key technologies for the Internet of Things in the cooperative project 'Semantic Product Memories' (SemProM). By the use of integrated sensors, relations in the production process become transparent and supply chains, as well as environmental influences, retraceable. The producer is supported and the consumer better informed about the product. The innovative basic concept of the Digital Product Memory is systematically adjusted to the strategies of the Internet of Things. It is based on semantic technologies, man-machine communication (M2M), intelligent sensor networks, instrumented environments, RFID technology and multimodal interaction.

The deployment of digital product memory creates significant added value through a multitude of possible applications along the entire product value chain. The SemProM project specifically looks into applications in the following fields: Manufacturing, maintenance, logistics, retail, and end user support. Project partners besides the German Research Center for Artificial Intelligence are: BMW Group Research and Technology, Deutsche Post DHL, SAP AG, Siemens AG, Globus SB-Warenhaus Holding, and 7x4 Pharma.

6 Conclusion

In this article we discussed the relevance of Digital Object Memories in the context of the Internet of Things. We argued that both concepts complement each other perfectly, as Digital Object Memories provide a rich knowledge source for object-centered applications in the Internet of Things, while in parallel the Internet of Things allows for an automated and continuous construction and updating of such memories.

We presented a general layered architecture which provides a unified model for the realization of Digital Object Memory services based on heterogeneous technological platforms. This goal is achieved by defining discrete layers of functionality and distributing the according responsibilities across the object and its environment. This architecture is flexible enough to also account for hybrid and composed memory structures.

Finally we showed a concrete implementation of a demonstration and evaluation prototype in the context of intelligent shopping assistance. Based on this prototype we showed how information from Digital Object Memories enables novel kinds of applications in the Internet of Things. On the basis of three hypotheses concerning interaction, desired service and privacy, we collected feedback from users of this system (visitors of a public presentation). On the positive side, this feedback confirmed to some extent our general assumption that there is an interest in applications of DOMs beyond the point of sale. Thus, the DOM's technical capability of collecting data continuously could be exploited by retailers for novel services beyond user support in a store. However, feedback concerning the interaction with DOMs emphasizes the need to integrate access mechanisms smoothly into technology people are familiar with. Furthermore, while the presented means of privacy protection were perceived in a positive way, there is only limited trust in such technology. Following feedback concerning preferred applications, this suggests focusing the application of DOMs to particular combinations of products and services, such as quality control.

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