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Bringing Augmented Artefacts out of the Laboratory

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Abstract The ill defined theory behind the design paradigm is the primary impediment of augmented artefact proliferation. In this paper we attempt to rationalize this design paradigm aspect from three dimensions and provide a clear and structured guidelines to augment everyday artefacts. First, we present a 3-step design guideline to select the appropriate augmentation role for an artefact. Second, we propose a layered artefact model as a collection of profiles to represent a physical artefact digitally; each profile encapsulates a specific augmented function of the artefact. This layered model ensures reusability and portability by abstracting transport, sensor and semantic levels of heterogeneity. Finally, we put forth a few HCI issues related to the augmented artefacts expressiveness.

Keywords Augmented Artefacts · Heterogeneity · Reusability · Artefact Model

1 Introduction

Augmenting everyday artefacts with sensors or actuators and building an instrumented environment have become a hot trend in ubicomp community. In fact, the smart object domain has matured over the years. Several successful prototypes and applications have already been demonstrated and even commercialized. Figure 1 depicts some of these augmented artefacts like MediaCups [5], Ambient Umbrella [1], Music Bottles [10], AwareMirror [7], Intelligent Spoon [2], Smart Furniture [20] etc. Unfortunately, none of these artefacts are capable of interacting with each other on the go, and cannot be integrated into one common application without special care. Moreover, there is minimum or no commonality among the design practices of these artefacts. One of the reasons behind this is that the augmented artefacts design is mostly motivated by the designers intuition. The ill-defined theories of ubicomp can hardly justify the appropriateness of the augmentations. Thus, the design practices of one project are rarely carried over to the next. We believe now it is the time, to approach this domain horizontally and formalize the design rationale of augmented artefacts on the basis of the existing prototypes.

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Fig. 1 Prototype augmented artefacts from various research projects

In this position paper, we look at the design aspects of smart artefacts from our experiences. We present a design guideline for role selection and development of augmented artefacts while discussing the heterogeneity of artefacts at semantic, sensor and communication level. Specifically, we propose a profile-based artefact model that can lead to a unified design increasing reusability and interoperability. Furthermore, we put forth a few HCI issues related to augmented artefacts that we believe would invoke interesting discussions in the workshop.

2 Some Issues with Augmented Artefacts

Typically augmented artefacts are fabricated with various kinds of sensors and actuators that suit their appearance and primary functionalities. This augmentation allows these artefacts to provide value added functionalities beyond their primary roles (so-called context like: state-of-use, environment attributes, etc.). Although augmented artefacts rely on some underlying sensors, they are distinct from sensor networking, where dedicated individual sensors create a federation to collect real world data. Augmented artefacts have a primary role in our everyday life and their augmentation allows them to play some additional roles. Consider a frying pan, its primary use is in the kitchen. However we can utilize the frying pan by augmenting it with some sensors to infer that its owner is in the kitchen or cooking while the frying pan is being used. These artefacts are independent of any dedicated sensing infrastructure but can create a federation among themselves thus forming a self-aware intelligent environment in a bottom up manner. These characteristics pose several research questions:

1. *Augmentation Role:* What augmentation role is suitable for an artefact, i.e. is there any way to map an artefact to some roles?
2. *Augmentation Method:* How to build an augmented artefact ensuring reusability, this question can be further subdivided into
   (a) How to present a physical artefact digitally?
   (b) How to select the appropriate sensors and actuators ensuring interoperability?
   (c) How to select appropriate communication mechanisms ensuring interoperability?
3. *Augmentation Expressiveness:* How to express an artefacts additional capabilities? How to augment an artefact that is self-explanatory and how does it affect peoples perception?
   Question 1 and 2 are system design issues and are the focus of this paper whereas question 3 is a pure HCI issue that we have further elaborated in section 5.

3 Augmentation Role

Designing augmented everyday artefacts by embedding sensors and actuators is highly influenced by the designers intuition. Because of this, it is hard to justify the ad-hoc selection of augmentation roles. This ad-hoc way also limits a designer in repeating the steps in building artefacts rapidly and consistently. In this section we provide a 3-step guideline to formalize this role selection method. The key point utilized for appropriate role selection is the relationship between a users interaction and an artefacts properties. The discussions in existing works show the catalogues of sensors to select the appropriate sensor for fabrication from target phenomenas point of view [6]. However, it lacks analysis of the earlier stage in terms of suitability of the artefact augmentation for the target phenomena, i.e. what kind of artefacts are suitable for observing the target phenomena, what kind of interaction is remarkable for observing the phenomena, what quality attributes are significant etc. Our guideline provides a systematic way in handling these questions. Namely, it provides a solution to answer the question What kind of phenomenon is the catalyst to augment an artefact accurately?" There are three steps to select the appropriate role.

1. *Step 1 Clarify the Required Functionality:* This step is to answer the basic question, What functionalities are required? As mentioned earlier, this functional requirement cannot be confined since it depends completely on the designers intuition and the target scenario. However, from a very broad perspective, the functionality can be of two types: sensor and actuator. The former is responsible for observing some real world phenomenon where the latter is responsible for causing some phenomenon in the real world. For example, in AwareMirror [7] the required functionality is to show some superimposed data/image in a mirror, in MediaCup [5] the required functionality is to identify the state of use of the cup and the condition of the cup. Therefore, first of all a designer has to clarify his/her requirements for the augmentation.
2. *Step 2 Analyze Artefacts Physical Property:* The next step is to analyze the target artefacts physical properties, i.e. size, shape, surface etc. Schmidt has provided an excellent insight of context patterns that can be observed by augmenting different kinds of real world objects varying in physical properties [18] and his observation can be used as a guideline for this phase to analyze the affordability of an artefact for the required functionalities. For example, providing mode-of-interaction context is suitable for AwareMirror, however it is impractical to augment AwareMirror for identifying Being-Carried context considering its size and shape. So, designers should assess carefully whether the target artefact provides the required functionalities considering its affordability.
3. *Step 3 Analyze and Map Artefacts Interaction to corresponding Phenomenon:* The final step is to analyze the specified usage to answer the question How to use it? How it affects the real world? The result of the analysis classifies the usage into primitives, which include holding, opening, closing, bending approaching, putting, removing, touching, leaving, pushing, pulling, rotating, shaking, leaving, storing, extracting, etc. For example, in the case of sitting on a chair, a user's hip is put" on the seat with some force, and the back is lean on the back seat i.e. touching. Each of these primitives relate to a physical phenomena. So, once the interaction primitives are identified, the phenomenon should be specified in parallel. For example, when something is put" on the surface, there might be a physical phenomena like the change of pressure on the surface, the vibration of the surface, noise, the change of temperature on the surface, the change of electric capacitance, etc. Clarifying the in-

teraction and corresponding physical phenomena allows a designer to augment the appropriate functionality to the artefact and to find the appropriate sensor/actuator fabrication position considering its primary interaction techniques and usage.

In the next section we look at the augmentation method of everyday artefacts.

4 Augmentation Method

Once artefacts roles are defined the next phase is to physically augment the artefacts by selecting appropriate sensors and communication protocols. It is obvious that we also need a software component that represents the artefact digitally, controls these sensors and interact with the external applications. Selecting the appropriate sensors for physical augmentation depends on many aspects, e.g. qualities, performance, form factor, cost, power consumption, availability, aesthetics, etc. The trade-off depends on overall requirements for the prototyping or product. An example sensor selection guideline that follows our augmentation role is explained in detail in [11]. The next phase after fabrication is to make those sensors/actuators talk to the external stimuli and applications. This includes the development of a software component that represents the physical artefact digitally. Unfortunately, there is no guideline or ideal structure for the development of these software components. As a result, this phase introduces several technical impediments, which are the primary reasons that limit artefacts reusability and interoperability. To understand what might be an ideal software stack, let us first look at the requirements based on the problems that can be found in the current augmented artefact research.

4.1 Heterogeneity Problem

Technically, everyday artefacts are augmented with various kinds of sensors or actuators to sense or affect some real world events and usually their behaviour is controlled by some external applications through some communication channel. This leads to three levels of heterogeneity.

1. *Sensor Layer Heterogeneity:* Several research group has proposed and commercialized various kinds of sensors nodes that are typically utilized while augmenting artefacts, like Smart-its [8], Cookie [9], SensorButtons [17], Mote [3], MITes [19], etc. Each of these platforms has different communication schemes, access and interaction methods. As a result, the artefact developed in one of these platforms cannot be ported to other platforms without rebuilding it from scratch. To make a portable and reusable artefact without considering underlying sensor platforms, we need a sensor abstraction layer.
2. *Transport Layer Heterogeneity:* In most of the scenarios of pervasive computing, multiple artefacts are integrated into one or multiple applications. In addition to augmented artefacts, these applications often involve regular home appliances (Refrigerator, Washing Machine, etc.), audiovisual devices (TV, VCR, etc.) or typical computing devices (Display etc.). These artefacts usually vary in their communication protocols to interact with the applications. Looking at the current practices, these protocols could be Bluetooth, ZigBee, IEEE 1394, IEEE 802.11 Wireless LAN, uPnP, etc. Thus, discovering or creating a federation among artefacts often causes incompatibility issues. To solve or hide this heterogeneity we need to have an abstraction layer that can provide a bridging mechanism among cooperating artefacts and can take care of protocol level translations.
3. *Data Layer Heterogeneity:* Due to the previous two issues, one obvious problem is the data semantics disparity among the artefacts. Artefacts disseminating data using Smart-its platform can not cooperate with artefacts disseminating data using Cookie platform, even though both platforms provide semantically correct data of similar phenomena i.e. temperature, acceleration, etc. To cope with this, we need a reference frame to unify the meaning of data from different platforms.

We argue that these three system level issues are the primary impediments that limit the reusability, integration and exploration of augmented artefacts.

4.2 Scenario Dependency Problem

Current practices typically augment an artefact with a specific scenario in mind. As a result the artefacts capability and augmentation is tightly coupled with the application scenario thus limiting its reusability. However, it is hard to confine a single augmentation for an artefact. Consider, Figure 2 where two ideal situations are depicted, a) one artefact with multiple roles and b) multiple artefacts with similar roles. In Figure 2(a) we have an augmented table that can play two additional roles: ambient display and proximity detector (whether some one is in front of it or not). In Figure 2(b) we have a mirror display [7] in washroom whose functionality can be triggered by any of the three augmented artefacts, e.g. a toothbrush, a comb or a razor. In both the cases, the software component that is representing the artefacts must handle these situations.

That means, an artefact must not be tightly coupled with the augmented functionality, like for each function, one artefact specific to one scenario. Instead, artefacts should be augmented in a generic manner and augmented function should be independent of the artefacts. In one artefact space, there might be multiple funcational features that are decoupled from each other within the

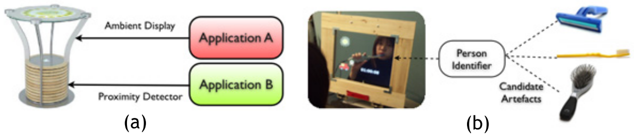


Fig. 2 One artefact with multiple roles and multiple artefacts with similar roles

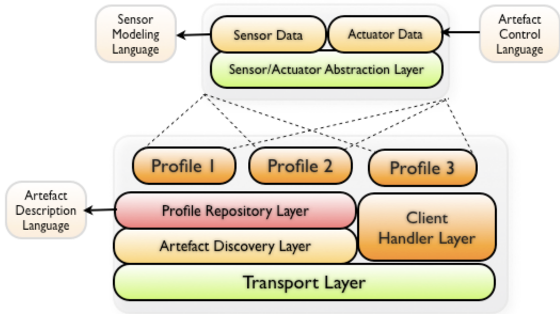


Fig. 3 Profile based layered model for augmented artefacts

same artefact space. These augmented features should be portable and generic to ensure reusability. Additionally, one application can select any artefact, whose functionality is suitable for the scenario in context.

4.3 Profile based Layered Artefact Model

Considering the two problems mentioned in the previous subsection, we propose a layered artefact model organized as a collection of profiles to represent an augmented artefact digitally. Figure 3 shows the structure of the model. The primary abstraction in our model is the notion of profile. As depicted in Figure 2(a), an artefact can provide multiple functionalities and each functionality is encapsulated into one profile. So, the profile is just a wrapper of an artefacts specific functional features. Profile is commonly used for defining services in different industry standards, for example: Bluetooth Profile, J2ME Profile etc. Our profile notion has the same meaning in the context of augmented artefacts. Our model consists of 4 layers. The bottom layer is the Transport Layer, responsible for hiding transport level heterogeneity. This layer abstracts industry standard communication protocols, and the artefact developer uses a unified interface on top of native communication libraries to interact with the external worlds. The next two layers are the Artefact Discovery Layer, and the Profile Repository Layer that handle the discovery mechanism and manage the collection of profiles respectively. Parallel to these two layers is the Client Handler Layer that takes care of the external applications requests by delegating to the appropriate profile. On top of these layers resides the collection of profiles. The profile itself is structured into multiple layers, where the Sensor/Actuator Abstraction Layer hides the heterogeneity of the sensor platforms that the artefact uses. Unified interfaces are provided atop this layer for the profile developers to wrap the profiles functional features.

In our model, three kinds of languages are used to express an artefact and to interact with it. The Artefact Description Language as shown in Figure 4(a) is the common language that describes the artefact (name, purpose, vendor, version, etc.) and all of its profiles (name, purpose, etc.) All these are soft typed and are coupled with qualifiers that can be used to know the real nature of these attributes. Each profile can play the role of a sensor, an actuator or both. For describing a sensor type profile the Sensor Modeling Language (SML) [16] is used. The primary strength of SML as shown in Figure 4(b) is its soft typed attribute, reference frame and parameters, using which the semantics of different sensor data platforms can be easily understood and interchanged. For an actuator type profile, Artefact Control Language is used. This is used as shown in Figure 4 (c) to express the states of the actuators, and the parameters to change the states along with their data type. Please note that, we have used the state attribute to abstract the commands semantics of the artefacts.

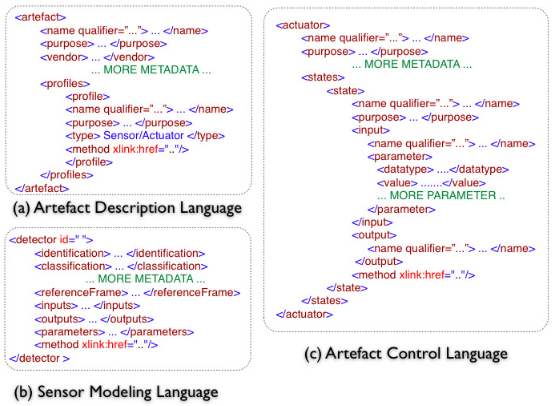
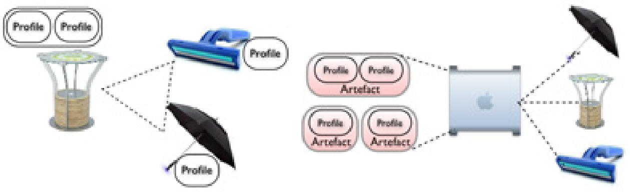


Fig. 4 Languages to express an augmented artefact digitally

The layered artefact model can effectively hide the transport and sensor level heterogeneity whereas the sensor modeling language and actuator control language handle the data semantics heterogeneities. Profile based design provides us the loose coupling between artefacts and its functionalities leading to a reusable and interoperable artefact design. As it implies, profiles are independent of artefacts and portable among artefacts, meaning one profile can be applicable to multiple artefacts, as long as the functionalities wrapped by the profile are suitable for the artefacts in context.

4.4 Location Modality

Once artefacts digital representations are clarified, the next phase is to decide where to put this representation, i.e. location of the software component. There are two choices: a) At the Edge (On-Board) b) At the Infrastructure (Off-Board) as shown in Figure 5. Both choices have pros and cons. In the following these are explained.



(a) At-the-Edge (b) At-the Infrastructure

Fig. 5 Location modality for representing augmented artefacts

4.4.1 At-the-Edge

At-the-edge or on-board means, the software component is built-in the augmented artefacts as shown in Figure 5(a). The augmented artefacts are already in the market like [1], so this approach is not anymore a future forecast rather in practice. The advantages of this approach are:

1. *Pre-configured:* Users do not need to consider about configuration. Once they buy the artefact they can use it instantly.
2. *Self-sustainable:* Since artefacts are manufactured and passed a quality control, these are robust in general.
3. *Less Maintainability:* These artefacts do not need special care or maitainance considering their robustness
4. *Aesthetic Appearance*

The disadvantages of this approach are

1. *Limited Capability:* Since these artefacts are pre configured, their functions are also limited. It is not possible to envision new capabilities using users intuition.
2. *Less Interoperable:* Considering the current practice, it can be reasoned that this approach might not provide enough interoperability unless similar models as proposed in section 4 are adopted.
3. *No support for Do-it-yourself (DIY).*
4. *Less support for rapid prototyping.*

4.4.2 At-the-Infrastructure

At-the-infrastructure or off-board means, the software component resides in a remote location while artefacts are only fabricated with sensors and actuators as shown in Figure 5(b). This is the most commonly practiced approach in the current smart object domain. The advantages of this approach are

1. *DIY Support:* Perhaps the most important advantage of this approach is DIY support. It is impractical to think that we will completely replace our everyday artefacts with augmented ones. Rather incremental replacement is a feasible approach. DIY is the best way to do it. We can think of buying a special profile package for an artefact and fabricating the profile component in the artefact following guidelines and configure it in a common infrastructure. Many furniture manufacturers like IKEA[1] promote the DIY approach and researches have already been done to support this approach [4]. A definite extension can be augmented artefacts.
2. *More Interoperable:* Since these artefacts digital identities are maintained in a common infrastructure, it is easier to handle the interoperability issue using a secondary infrastructure like uMiddle [12].
3. *Rapid Prototyping:* This approach supports rapid prototyping, and clear evidences are the numerous augmented artefacts in various research projects.
4. *Versatility:* Since the augmentation is in users hands and motivated by their design intuition, this approach leads to a versatile use of an artefacts.

The disadvantages of this approach are

1. *Maintainability:* These artefacts require maitainance by the end users and are fragile due to adhoc fabrications
2. *Configuration:* This approach needs authorship for configuring the artefacts that might not be easy.
3. *Less Aesthetic Appeal:* Due to the adhoc fabrication, these artefacts may not have an appealing appearance, which according to Norman may lead to degrading artefacts prospective potentialities [14, 15].

Considering the current practice and technology, it can be inferred that At-the-Infrastructure option is more suitable for research endeavors especially for its rapid prototyping and DIY support. In the next section we will look at some HCI issues that further challenges the convergence of augmented artefacts.

5 Artefact Expressiveness

In the previous sections, we have discussed the system level issues for building augmented artefacts. An equally challenging aspect is the HCI perspective of augmented artefacts. We believe even if the system level challenges are met, the major impediment that will limit the proliferation of augmented artefacts is human perception of augmented artefacts, unless these issue is approached in parallel. In this section we put forward some HCI issues that we believe will instigate interesting discussions in the workshop.

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[1] http://www.ikea.com

Perhaps the most challenging HCI aspect of augmented artefacts is to define an appropriate way to express an artefacts augmented functionality naturally. By natural we mean, an interface that activates the cognitive and cybernetic dynamics that people commonly experience in real life, thus persuading them that they are not dealing with an abstract, digital media but with physical real objects. This results in a reduction of the cognitive load, thus increasing the amount of attention on content. The critical question is how to ensure this? How to ensure that the augmented artefacts affect human perception in the same way regular artefacts do and their augmented functionalities are self-explanatory? We consider human perception of everyday artefact consists of 3 phases: understanding, learning and using an artefact. Understanding and Learning are basic cognitive activities of the human brain, which construct human mental model towards an object. Once these two phases are mastered, human approaches the next phase, i.e. using the artefact. Since human already has mental model for everyday artefacts, we must have to make sure that the augmentation matches that mental model. So, that the interaction with an augmented artefact comes naturally. As pointed out by Norman [13], one way to approach this issues is to build a solid conceptualization model of the augmented functionalities of the artefact that are consistent and coherent with users current mental model and present the conceptualization model to the user through instruction materials. However, this is an open problem, and we expect to discuss this issue in the workshop to consider other viable approaches.

6 Conclusion

Augmented artefact research is approaching towards a convergence stage. Many prototypes and constituent sensors/actuators are built and demonstrated. However, there exist a missing link among these research endeavors that limit the reusability and interoperability of these artefacts design and functionalities. In this position paper, we have presented augmented artefact selection and development method based on our experiences. A profile based layered artefact model is presented that hides heterogeneity and ensures reusability and portability. Also we have discussed several other aspects of augmented artefacts. We hope the content is inline with workshops goal and will instigate stimulating discussions.

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