A Context-Aware Adaptation System for Spatial Augmented Reality

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Abstract. From an HCI point of view Augmented Reality (AR) displays have a very specific characteristic. The shown information consists of a virtual and a nearly uncontrollable and cluttering real part. Thus, AR visualizations can be ambiguous, imprecise, or difficult to understand. To avoid this, the presented project shows a systematic method for adapting AR visualizations to the user's needs and perceptual properties. Therefore, we firstly reused and extended established 2D visualization models with AR specific visualization parameters and secondly incorporated known AR specific perception facts to set up an AR smart home control system in a kitchen. The control system involves spatial AR displays (sAR) and makes use of context information like current user tasks or the user's position. The goal is to provide a generic approach of displaying unambiguous AR information at the right time and location without overwhelming the user.

Keywords: Spatial Augmented Reality, Information Visualization, Perception, Evaluation, Context-Awareness, Smart Kitchen Displays.

1 Introduction

By definition Augmented Reality combines virtual information with the real world in real time and with a content-related connection to the point where it is presented [1]. This task still imply difficulties for hardware and software because of their (physical) constraints. This is one of the reasons why AR technologies have not been usable for a long time. But current system developments show the applicability of AR via mobile phones or light-weight Head-Up-Displays (HUDs). However, beside the still remaining problems like tracking, registration, occlusions, etc., virtual superimpositions with AR technologies also involve information visualization (InfoVis) as a main task. Currently the shown AR information typically is what the appropriate (rendering) system is able to provide sometimes even without following all parts of AR definition (see Fig.1). But for most applications these presentations are not the result of an evaluated visualization synthesis. Thus, users oftenhave problems to understand the AR information which is a problem not only for safety-critical contents.

V.G. Duffy (Ed.): Digital Human Modeling, HCII 2011, LNCS 6777, pp. 417–425, 2011.

Fig. 1. Example for bad superimpositions. Most notably it is unclear which restaurant in the user's field of view is meant. Also the navigation list on the left side does not have a specific relation to the real scene thus it does not fullfill the AR definition in a strict way. In detail this means there could not be made a distinction between this "AR display" and any other mobile device with the shown applications.

The AR InfoVis is the focus of our project UARKit (Ubiquitous Augmented Reality Kitchen), the user-centered and context-aware adaptation system for sAR displays. The UARKit project follows the UAR paradigm [9] where a lot of AR (interaction) concepts (Tangible, multimodal AR) are brought together. As an additional specification we only use spatial AR devices. Spatial AR (sAR) only uses fixed projection systems or HUDs instead of mobile devices to keep the user from wearing heavy display and camera systems. Thus, the sAR devices present information at the location where they belong to in a user friendly way. But to avoid overwhelming the user with information projections a control system will accomplish the visualization synthesis based on constraints of human perception, the AR specific visualization guidelines, the user's position, and the context.

The following two sections will explain how sAR visualization can be adapted to user's perception. They relate to 2D visualization parameters and empirical experiences with commercially available AR display technologies. To implement a visualization synthesis for the UARKit project we carried out a systematization of these parameters and tried to find out open questions concerning specific sAR visualization characteristics for the kitchen application. The fifth section therefore also refers to additional AR perception experiments. Section six will summarize and explain the UARKit adaptation system.

2 Theory of 2D Vis Parameters and Their Transferability

In most cases AR uses 2D display surfaces or position dependent 2,5D presentations to simulate 3D. Thus, AR InfoVis deals with similar problems like 2D InfoVis. To find out the transferable rules of 2D InfoVis it has to be distinguished between different aims of (s)AR applications. Many of them do not need an abstraction of the virtual visualization because the goal is to present a virtual object very realistic. This is not the aim of visualization adaptation. Thus, for our project it is necessary to reduce the set of proposed AR visualization types with a categorization based on their function. Following Dubois and Nigay [5] two basic concepts lead to four categories (see Table 1).

Table 1. The four AR types with the tagged aim of this work (grey)

Task Focus \ Nature of Augmentation	Execution	Evaluation
Virtual Object	Manipulating a real object which is augmented with virtual functions	Realistic Graphics
Real Object	Virtual Manipulation of a real Object, like virtual cut& paste with virtual text on a real peace of paper	Virtual Information about real Object

The visualization adaptation only makes sense for the virtual information about the real object (No. 4). This incorporates abstraction of the information and thus has to make use of parameters for a reduced form of information presentation. The other applications of AR information presentation do not relate to a real object or want to manipulate the real object in a virtual way, which means that the augmentation again leads to a virtual object. This is not the aim of this work because virtual or abstract objects could have any representation a designer creates (e.g. file icon on a desktop).

The research field of (2D) InfoVis solves similar visualization problems for two-dimensional virtual (desktop) displays.

It is mainly based on findings concerning perception (e.g. Gestalt Laws [13], Semiology of Graphics [2], etc.) and combines parameters like a special color or shape of the presented information to enforce the right interpretation of data.

For 2D visualization basic models determine visualization parameters and dependencies as a given set which later is used for visualization adaptation for a specific application. Typically these models contain: visualization possibilities ranging from textual to graphic forms and from static to animated forms. They also involve image variables like plane, size, value, and relation of the presentation as well as differential variables of the image like texture, color, orientation, and shape. All parameters are basic forms except value and relation. They are formed with a selected combination of the others.

To specify the parameters (which color, orientation, or shape, etc. to present) these models also determine (domain related) dependencies. These are the anchors for choosing the best possible visualization. The dependencies involve user skills (from novice to expert), data types (object data, attribute data and meta-information) and data relationship structures (linear, circular, ordered-tree relations, etc.). Other dependencies describe task types (based on task types of Shneiderman [10]), interactivity types, and contextual information like user's life experience, history, intend, need, and devices.

For this model and others a large set of rules exists to optimize the information presentation. Each gives guidelines to specify single parameters in general or for a special purpose. To set up the visualization for a given system, the developer has to determine the current dependencies to reduce the set of possible rules which have to be applied for his task. Different approaches exist to automate this determination like visualization exploration models [7] or expert systems.

2D InfoVis parameters are not naturally transferable to AR technology. One general rule says for example that graphic visualizations are always better than annotations only (textual form). But for a virtual augmentation it is relevant how cluttering the background is at the proposed location. Sometimes a graphical visualization of the information about a real object is also very complex and consists of a lot of (heterogeneous) parts and thus is not perceivable in front of a cluttering background. At this point an annotation might help because of its homogeneity. So it has to be tested which 2D parameters are transferable and whether they have to be organized into a hierarchy for AR specific conditions.

Thus, for our project we collect a list of rules and set up a knowledge base which follows the principles of good visualizations (expressivity, effectiveness and appropriateness) and those of known AR perception characteristics.

3 Established AR Specific Vis Parameters

The existing InfoVis models only involve parameter to optimize 2D (desktop) displays. With them it is possible to lead attention from one virtual information to another (in a relatively small virtual space) or to facilitate the interpretation of virtual data relationships like e.g. presenting them in a 2.5D-tree structure which is virtually rotatable. But if the information consists of virtual and real parts it should be distinguishable from other real information of the scene. So firstly the user has to recognize which part of the real world (and which not) belongs to the virtual augmentation. Then he has to understand the meaning of the superimposed information. An additional difficulty is that in most cases the additional virtual information is not complete or self-explaining without its real part.

Many AR parameters of visualization already facilitate the handling of these tasks. Typically these parameters belong to a meta-level of the basic InfoVis parameters which means they combine e.g. color and shape in a specific way to achieve the right interpretation.

These (still incomplete) parameters and appropriate exemplary rules are:

- *Transparency.* When using transparent superimpositions maximize contrast between (transparent) virtual and real parts of information, background must be as homogeneous as possible to improve perception [6].
- *Motion Parallax.* Subjects underestimate sizes and distances of objects, while they are moving (while motion parallax is involved), this is similar to a known Virtual Reality effect [8].
- *Cognitive Tunneling.* Users tend to fixate the virtual displayed information and miss events in the real scene. This effect is multiplied by heterogeneous and distributed superimpositions [3].
- *Conformal Symbology.* Perception could be improved by superimposing conformal symbology at the location of the real object it represents [3].

- *Nonconformal Symbology.* Should be presented with distance to the relevant object in reality to keep it visible [3].
- *Clutter.* Clutter causes cognitive tunneling. Highlighting important things and lowlighting (reducing luminance and contrast) less important things helps to avoid this [3].
- *Depth Cues.* The usage of depth cues improves estimation of proposed projection depth. Pictoral cues are e.g. interposition, linear perspective, and density of texture [4].
- *Gestalt Laws.* Very common rules for supporting the connection of (displayed) information parts (in this case real and virtual parts) [13].

4 Experiments for Missing Parameters and Visualization Synthesis

With collecting and formalizing general rules as a knowledge base the foundation is made for a rule-based expert system which is able to automate the decision for the best possible sAR InfoVis. However, searching visualization guidelines for different types of information in a complex setting will generate a huge amount of rules which is a serious problem. We therefore use the context of the project UARKit and the incorporated sAR display technologies to reduce them. The analysis of missing parameters is the result of a reduction process of possible types of information, user positions, context data, and display limitations.

Furthermore, with the use of a fuzzy expert system (fXPS) we do not need a complete decision tree with only consistent rules. Fuzzy inference engines operate with approximate or plausible reasoning which need less (and fuzzy defined) rules to produce the most feasible result (visualization) for a given set of accessible and perhaps inconsistent rules. Another advantage is to allow rule definitions which are not only true (=1) or false (=0). Terms could be defined nominally with also using any value between true and false. For example the information can be very important, average important, or unimportant but nice. Thus, the visualization has to be flashy, noticeable or only visible. In this way the XPS is more suitable for the real application UARKit and solves the problem of inconsistency of all the rules for visualization.

The visualization syntheses we propose is the result of the fuzzy inference engine of the XPS. With a draft of its architecture and its decision principles we also found out open questions for optimized perception of sAR InfoVis in the context kitchen: For further classification of usable visualization parameters at one point of the context analysis it has to be decided whether the real object the virtual information belongs to is real and exists physically or is an abstract idea in the real setting like a direction where a user has to go. The next decision step for a physical object has to judge about the kind of evaluation or execution. As already mentioned the meant object first has to be recognized in an efficient way. For this we have to find out appropriate rules for visualizing the needed saliency for a real object and while doing this define specific parameters. For the abstract type of information in the use case of the UARKit project we used the indoor navigation exemplarily.

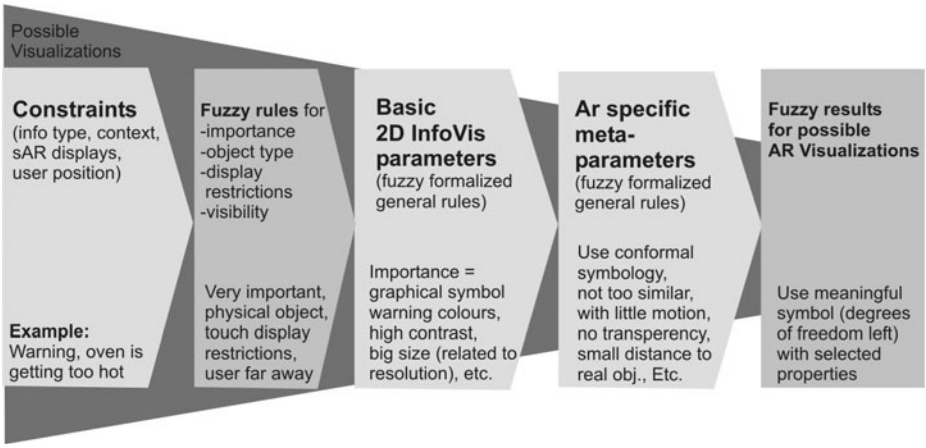

Fig. 2. Operating mode and example of the Fuzzy Inference Engine: Getting an AR visualization from knowledge bases (light grey) and current associated rules (darker grey) for one state of visualization

The open questions concerning missing parameters for the project UARKit are on the one hand related to real object recognition for physical manipulating tasks. On the other hand they relate to the comprehension of an abstract idea (in this case a direction) and execution of the demanded indoor navigation task. In both settings we testet a derived parameter from (non)conformal symbology we call *redundancy* and the parameter *similarity* as a combination of realism and Gestalt Laws.

Redundancy connects noncorformal and conformal symbology with merging the proposed rules of both and therefore reduces clutter. The meant object is augmented where it is located but the whole augmentation is presented with a distance to the visible real object. Similarity summarizes the Gestalt Laws related to the characteristics of AR visualizations (continued textures, similar motion, same or similar colours etc.). Furthermore, it incorporates the degree of used realism in the virtual superimposition because of the unsolved question how real the augmentation must be to facilitate perception.

4.1 Building Block Experiment

In this experiment we tested the influence of varied redundancy and similarity while presenting augmented markers on building blocks in a fixed building block setting. The subjects had to recognize which block was meant on the shown AR visualization and predict where to put it in an imaginary rebuilding task.

We found out that redundancy brings no advantage when a simple contour could be presented but there is no decline in performance while using redundancy. Furthermore, distances between representations and real object decrease performance. So conformal superimpositions are preferred but only if they are distinguishable from the real object. An augmentation thus should be of average similarity to improve detection of it but keep the relation between it and the real object. Such an augmentation is even as good as the usage of the common contour.

4.2 Indoor Navigation Experiment

In this experiment the subjects had to find different objects distributed in one room and therefore got varied projected navigational hints [12]. After determining AR hints based on a questionnaire we compared less redundant with redundant visualizations (arrow vs. maps) to examine the effect of a varied redundancy. The analysis shows that there is no difference between them for performance variables. On the other side the feedback of the user shows that visualizations which are more redundant (maps) are preferred. The arrow was found quite inexact and users are very familiar with using navigation systems and appropriate maps. But within the scope of the provided Smart Home scenario both visualizations are equally applicable.

The second evaluated parameter was the realism of the visualization. We therefore presented two types of maps (schematic and textured version). The results show again no effect on the performance of the user. Some participants reported not even having recognized different types of maps. Accordingly we could not find a preference for one of the maps after analyzing the questionnaire. Thus, we conclude that there is no necessity to make a virtual information as real as possible for the AR type 4 (see section 2.

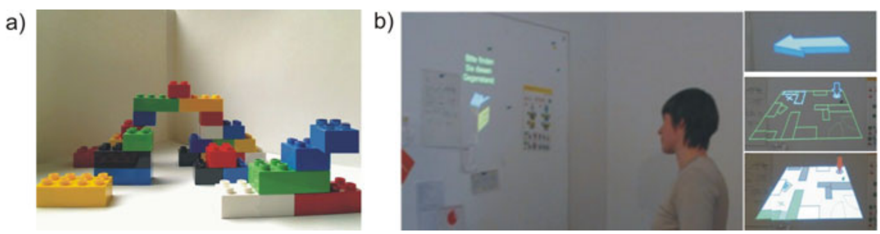

Fig. 3. Settings in the two experiments a) Building Block setting with augmented marker (blue block on the right side) b) projections and different hints for indoor navigation

5 UARKit System

The proposed context-aware presentation system is the core of the development of a sAR system in a Smart Home Environment. It will be integrated in a kitchen that involves different spatial AR displays and interaction paradigms (see Fig. 4) as well as diverse but fixed tasks. The context information therefore consists of user's position, state of the current user task, relevant light conditions for information presentation with projections and displays with few contrast, and information about objects in the kitchen (amount of needed ingredients for a meal, positions of needed tools, etc.). Context data is registered by sensor data and a context model for steps of user tasks.

For example we incorporated an intelligent floor projection which changes the location and content of a floor projection. It visualizes an information based on the position of the user and whether the perception would be efficient when light conditions, physical obstacles, and/or his distance to the projection are taken into account [11].

Fig. 4. Kitchen of the UARKit project

The software for user adaptation of the sAR visualization is Java-based with the architecture of a Blackboard system. It incorporates different knowledge sources (KS) for information management which itself solve parts of the problem independent from each other. Thus the system is platform independent and allows highly flexible configurations and problem solving strategies. Even though is is not tied to the type of problem. Thus, the setting kitchen could be replaced by the setting of an industrial factory. Furthermore, the Blackboard system is able to deal with all the different parts of information which lead to one visualization. The knowledge sources solve the tracking, handle the context model, the database for display restrictions, etc., and provide their current results for every other knowledge source. This agent-like behavior makes it easy to replace one component, when parts of the context or the task are changing.

The fXPS is one of the knowledge sources and gets the needed information for the inference engine from the other KS. As a result it provides the current visualization which is displayed by the KS which handles display management.

However, with the decision for the Blackboard system the foundation is made to develop a multi agent system which is the next step towards a functionality based on learn algorithms. But moreover we keep the UARKit system highly flexible and scalable for the generic approach of a user-centered adaptation of sAR visualizations.

6 Summary and Outlook

The presented approach of the UARKit outlines a generic idea of adapting spatial Augmented Reality visualizations. Therefore, we analyzed 2D InfoVis guidelines and tested their applicability for sAR concerns. Additionally we extended the resulting set of rules with AR specific knowledge from own and external experiments. Afterwards, we reduce this immense number of rules while using established methods for rule reduction based on the context of our application. The usage of fuzzy formalization of the remaining rules also facilitates the handling of the proposed expert system concerning consistency and completeness.

The chosen architecture for UARKit system design supports the component character of the involved problems like tracking, context model, sensor monitoring, etc. and the fXPS. It solves the problem of scalability and provides the possibility for exchanging components to adapt the system to other applications, user tasks, new findings concerning AR visualization adaptation. Furthermore it leads to multi agent systems and appropriate learning strategies which is state of the art for Smart Home Environments.

Acknowledgements. We want to thank the Deutsche Forschungsgemeinschaft, the Chair of Human-Machine Systems Berlin, and prometei for their support.

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