A Novel Infrastructure for Supporting Display Ecologies

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Abstract. We introduce a novel approach for display ecologies that aims to support users in presentation and discussion scenarios by applying assistance from Smart Meeting Rooms (SMR). We present an infrastructure that allows multiple users to easily integrate their mobile devices into the device ensemble of a SMR and to utilize its large displays to show contents like slides, pictures and other data visualizations. With a tailored editor, multiple users can easily share contents and interactively coordinate the display of information. The content is automatically distributed to the displays of the SMR based on user-defined spatial and temporal links between contents as well as on semantic networks. Further, intention recognition is used to automatically adapt the representation of contents with regard to the current situation. In this way we provide a user-driven smart steering that supports users by automatically reducing their effort to configure and to work with display ecologies.

1 Introduction

The increasing spread of mobile devices such as personal laptops, smart phones or tablets, and the increasing number of large public displays provide new ways to distribute and access visual representations. When multiple such devices are collaboratively combined in order to create, share, and display several views they form a so-called display ecology. Such environments provide the technical basis for distributing different types of contents across multiple displays, allowing users to share their slides, documents and images. In this way, presentation and discussion scenarios are well supported. This can be very helpful in various domains. However, in a recent survey [1] on supporting visual analysis through display ecologies four inherent challenges are described that can be summarized as follows:

- *C1*: The user must combine multiple displays into one holistic space.
- *C2*: The user must transfer different data and views for coordinating information across displays.
- *C3*: The user must link certain views across different displays.
- *C4*: The user must add and remove displays as well as particular views on demand.

Our aim is to address these challenges. We want to reduce the burden of the user by introducing a novel infrastructure that enables a **smart steering** of dynamic display ecologies. This means, we want that users only need to specify layout constraints, whereas display combination, information distribution, and dynamic layouts are computed automatically.

The background for our work are presentation and discussion scenarios in a smart meeting room (SMR). Smart meeting rooms are environments in which heterogeneous display devices (projectors, stationary and mobile displays) provide abundant space for representing views. Tracking devices and sensors deliver several types of information such as user positions or view directions. Associated software tools provide customized user assistance by i) evaluating sensor data to recognize certain situations and reason about the users' intentions, ii) integrating additional displays and other devices into the existing device ensemble, and iii) transferring data between multiple devices on demand. However, in order to fully take advantage of these capabilities in terms of using a SMR as a display ecology further investigations are required.

In this paper we focus on supporting presentation and discussion scenarios. Our approach is built upon the infrastructure of a SMR and consists of three components:

- An editor enables a user-driven coordination of information. So-called spatial and temporal links between different contents can be added interactively. In this way spatial and temporal constraints are defined to steer how contents should be arranged on the available displays and how contents should be replaced over time.
- A semantic description includes one or more semantic networks. Each network describes a particular topic. The nodes of such a network represent individual parts of the content. Related nodes are connected via so-called semantic links. Semantic links are either defined by the user or extracted automatically. They will be used to arrange views or to support search for additional contents during a discussion.
- A support component provides methods for recognizing a user's intention, assigning views to different displays and generating layouts. These methodes enable a high degree of customized user assistance.

The three described components enable a smart configuration of display ecologies in a smart environment. In the following we will discuss them in more detail.

The remainder of the paper is organized as follows. Section 2 gives an overview of the background and related work. Section 3 describes our setup and discusses the problems to be solved. The editor component as well as the semantic description are presented in Section 4. Since we focus on user assistance two separate sections explain the automatic computations: Section 5 describes the distribution and layout of views and Section 6 discusses the use of intention recognition to support dynamically changing discussions. We conclude the paper with an overview of the implementation in Section 7 and a description of possible applications in Section 8.

2 Background and Related Work

A key property of smart environments is the provided assistance [2, 3]. Examples are smart homes [4], applications in health-care [5], assistive systems that focus on lecture scenarios [6, 7] and in particular smart meeting rooms [8, 9], which record meetings for archiving, organizing and automatically summarizing the contents. Typically, audio-visual recordings are applied, although sometimes further context information such as activities or attention are tracked as well. However, the available assistance in SMRs has not yet been leveraged to foster display ecologies for visualization, presentation, and discussion.

To incorporate personal contents from mobile devices in SMRs, systems were developed to easily share windows or certain views from mobile personal devices and to display these views on the screens of the environment [10–12]. In such systems the large displays of the environment serve as a kind of shared extended desktop of the personal devices. Views can be exchanged using a local network or the Internet [12]. In addition, local inputs might be transmitted to the displays to enable multiple users to operate a single application [13, 14]. These approaches can greatly support collaborative work and allow users to jointly create new contents. However, these systems still rely on much manual user interaction to define where contents are to be presented in the environment (which display) and on the displays (which position). Window managers and automatically generated layouts can be applied to reduce user interaction [15–17]. These approaches address collaborative data exploration and visual analysis by supporting the user in determining where manually selected contents should be displayed. However, they lack assistance for quickly accessing contents during a meeting.

Chung *et al.* provide a comprehensive overview on different approaches for display ecologies [1]. They describe challenges, and design considerations, and summarize the fundamental approaches based on the tasks at hand. This overview makes clear that only a few approaches focus on supporting users by automatic configuration. Software that is designed for advanced, collaborative work in display ecologies lack the capabilities to manage dynamic device ensembles and to incorporate support from assistance systems and situation recognition.

We conclude that current display ecologies do not utilize the advanced capabilities of SMRs. On the other hand SMRs mainly support dynamic hardware configurations and interactions, rather than addressing a sophisticated presentation of information. We aim at bridging this gap by (1) providing a way to easily integrate users' mobile devices and contents into an existing display ecology, (2) providing constraints on how to use them ,and (3) applying automatic assistance to display these contents with respect to the current situation.

3 Setup

Our Smart Meeting Room (SMR) is a smart environment with many different devices and a complex infrastructure. Up to seven projection screens can be used in parallel. A video matrix crossbar connects up to nine user VGA inputs and seven VGA signals from a central server to the projectors. In practice it has been shown that it can be still a problem to effortlessly connect user devices to projectors. Most common problems are the mix in standards and available connectors and adapters (VGA, HDMI, DVI, DP) and technical incompatibilities. Therefore, three miniature PCs are directly connected to the seven projectors. They act as an interface between personal devices and projectors. In this way, views from different personal devices can be shown on the displays of the SMR immediately and simultaneously. The personal devices are connected to the infrastructure via Ethernet and Wi-Fi. The sensors and actuators of our SMR provide,

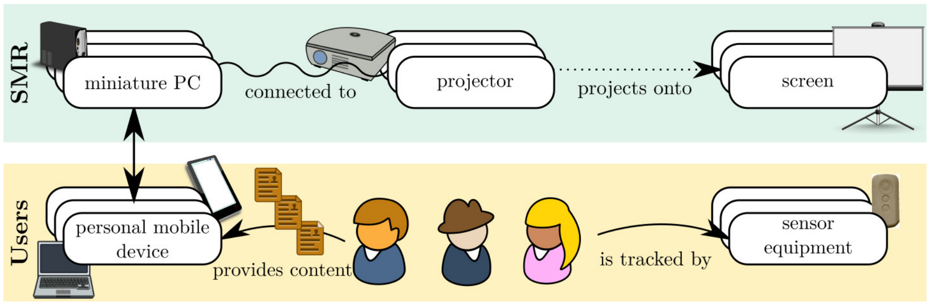

Fig. 1. Overview of the display ecology with the devices of our SmartLab and the personal devices of the users.

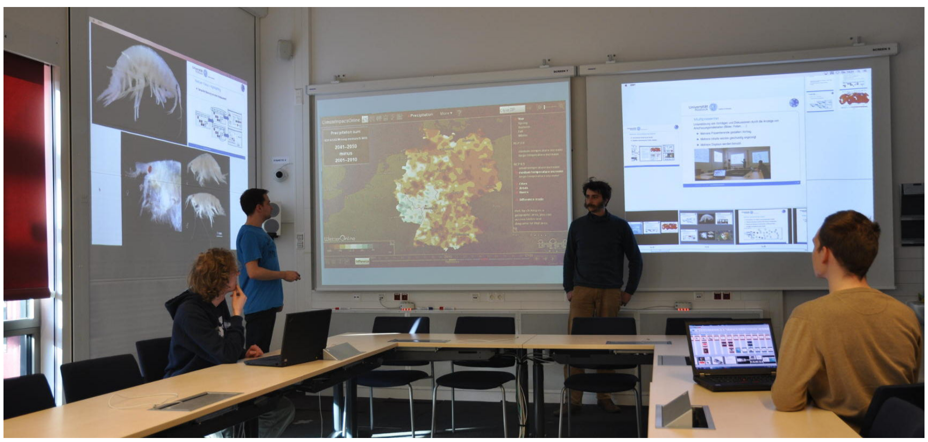

Fig. 2. Photograph of the Smart Environment in a meeting situation.

for example, information about user position and enable control of the screens and projectors.

The infrastructure of the SMR is controlled by a middle-ware [18] that implements several paradigms for coupling the components and providing control of the environment. Direct message exchange, event dispatching and publish/subscribe provide flexible communication between devices, services and applications. Applications are deployed from a web server using Java Web Start technology. This way, users can just enter the room, open their web browser to connect with the infrastructure, and start their applications to generate views to be shown in the SMR. Figure 1 gives an overview of the setting we are using. Figure 2 shows a photograph of the SMR.

In summary, our SMR realizes the combination of displays and personal devices into one holistic space (*C1*), the update of the device ensemble after adding or removing displays or personal devices (*C4*), and the transfer of information (*C2*). So, three of four challenges summarized in Section 1 are already addressed. However, the semantic coordination and linking of views of multiple users on multiple displays is still an un-

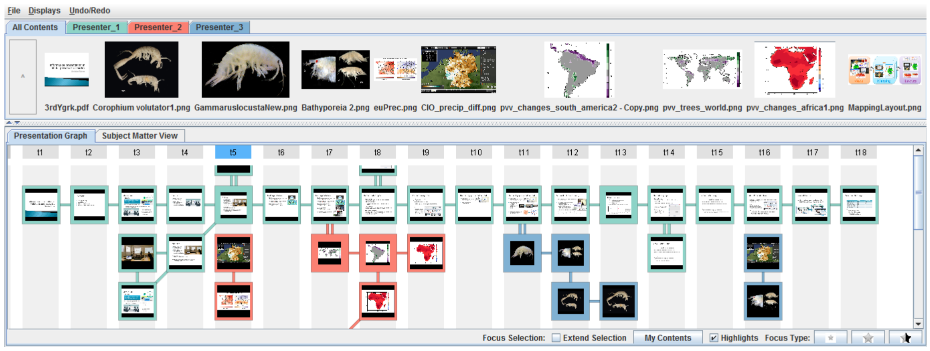

Fig. 3. The editor UI provides content sharing via the content pool (top) and allows modification of the presentation graph (bottom).

solved problem. The users need a way to steer which content should be displayed and how it should be laid out to generate meaningful arrangements. An appropriate interface is needed that supports the organization of contents by defining different types of constraints. We will discuss this issue in the following section.

4 Interactive Coordination of Information

To collaboratively utilize a display ecology users should be enabled to steer *which* content parts should be displayed and *how* these content parts will be arranged on the displays. To address this issue, we have developed an editor that supports 3 tasks: i) collecting the contents to be displayed, ii) linking content parts to steer the layout and iii) searching for related contents. The editor can be executed on any personal device. In this way, users get individual access to the different contents of the presentation, and furthermore, any user can contribute to the presentation with own contents. The user interface of the editor is shown in Figure 3. The top row supports the gathering of contents. It shows an overview on the so-called content pool, which contains all files that can be published. All provided files of all users are symbolized with small thumbnails. New contents can easily be added to the content pool by dragging local files into the content pool. These new contents are then automatically transmitted to other devices of the SMR via the middle-ware. The content is automatically grouped with regard to the contributing users. Tabs are used to group contents by user.

The bottom of the editor UI gives an overview of the presentation graph. It supports the linking of individual contents to steer the display of the presentation. For this purpose, contents are interactively selected from the content pool and dragged into the presentation graph. Relevance values can be assigned to emphasize information of particular interest, which will then be prioritized by assigning more display space to them. To steer the final layout, the individuals contents need to be set in relation. A user can easily define spatial and temporal links by interactively drawing a line between thumbnails. A spatial link specifies a spatial constraint: Connected contents are to be displayed in spatial proximity. A temporal link represents a temporal constraint: Such

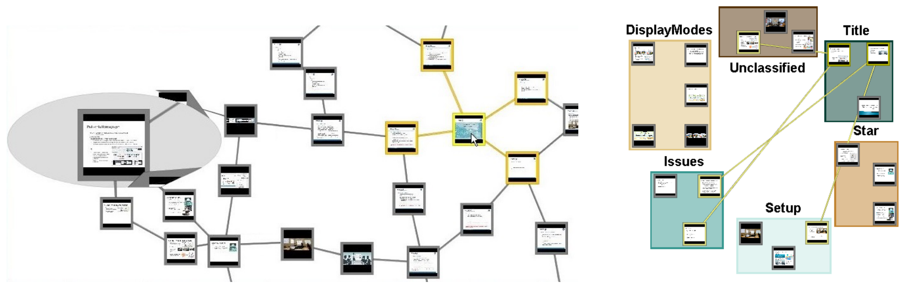

Fig. 4. The semantic network allows quick access to related content. Left: An overview allows to explore the structure of the semantic networks. An integrated lens provides a detailed view of a content. Right: An attribute based layout allows to search for particular contents and to explore relations with respect to specific attributes.

contents are linked in the chronology of the presentation and should therefore be displayed at roughly the same position. In other words, successive content is shown in a stable location.

The editor interface supports the generation of presentations. However, during a discussion, often further information that belongs to the topic could be required. To support the searching for related contents, a semantic description is provided. The semantic description contains one or more semantic networks each belonging to a particular topic.

A semantic network describes the additional connections between slides, pictures and other contents. Contents are connected, if they are about the same subject, if one content complements another content, or if there exist other relationships, e. g. based on the document structure. The semantic description contains every content that was shared by any user, regardless whether it is currently displayed or not. A content may be used more than once in the course of a presentation, but the semantic description contains it only once. The semantic description can be used in two ways: i) Semantic links can be used to search for related contents with regard to a particular content of interest. ii) Semantic networks as a whole can be used to get an overview of all related contents regarding a particular topic. Figure 4 shows the visual representation of a semantic network.

The semantic networks can be created or provided in several ways. First, existing semantic networks can be uploaded by the users. Second, users can interactively define semantic links between content parts either by drawing lines in the visual representation of the semantic network or by using the editor view of the presentation. Third, semantic links can be extracted automatically. We add links based on keywords, the table of contents, the structure of the text (e. g., in sections and subsections), the embedding of other contents within the document hierarchy (e. g., pictures in a PDF), hyperlinks, references to the cited literature and so forth.

In summary, semantic networks serve as a basis to link views automatically across several displays. Spatial and temporal links, on the other hand, steer the configuration of layouts. This will be described in the following section.

5 Automatic Content Distribution and Layout Generation

Our aim is to reduce the burden of the user. To this end, we provide an automatic computation of the display. This includes two tasks. First the individual contents need to be distributed, i.e. they need to be assigned to the displays. Second, all contents that will be shown on the same display need to be arranged. The automatic configuration is based on user-driven constraints, i.e. the defined temporal and spatial links as well as the assigned relevance values. Based on our previous approaches [19, 20] the configuration is determined by maximizing a quality function Q. It is defined as the weighted sum of the spatial proximity quality Q_s, the temporal quality Q_t and the display quality Q_d.

$$Max : Q = \alpha \cdot Q_s + \beta \cdot Q_t + \gamma \cdot Q_d$$

Here, the spatial proximity quality Q_s is high if positions of views that are connected by a spatial link are close to each other. This ensures that the calculated layout places these contents next to each other. The temporal quality Q_t rates how much the content distribution and layouts change when new contents are added or removed. If contents are moving too much on the displays, users could lose the focus on specific content of interest. Therefore, the temporal quality is high if temporally linked contents roughly stay at the same displays and positions of a layout. Finally the display quality Q_d quantifies the visibility of each view. A good layout should place contents on displays, where (most) users are able to see them well. To accomplish this, we consider the display size, the position of the displays in the room, the position and viewing direction of the audience and the size of a view in the generated layouts.

By adjusting the weights α, β, and γ, users can steer the influence of spatial, temporal and display quality on the layout generation. Thus they can decide whether the automatic layout calculation should produce layouts that tend to place related contents side by side, layouts that change as little as possible when views are added or removed, or layouts that ensure a good visibility of views. Adaptations of the weights or of the underlying constraints are automatically recognized and result in an immediate update of the content distribution. Layout calculations and updates are realized at interactive rates (~30 Hz). In this way users get fast feedback to their adaptations.

6 Intention Recognition and Discussion Support

In dynamic discussions, it is not uncommon that users have to fequently change visible content compositions by adding or removing contents (*C4*) and adapt the layouts on the displays for certain tasks (*C3*: link and compare visualizations). For this they have to interact with various devices and operate the editor, which allows for a flexible configuration. We aim to reduce the manual effort required to do these adaptations.We support various tasks with customized user assistance based on the capability of our SMR. For example we support the following typical tasks:

- *Navigation to a particular content* is supported by automatically:
  - Showing a temporal outline that can be used to bring up previously shown content compositions (see Number 2 in Figure 5(b)).

(a) Views of particular interest can be highlighted by increasing their size and desaturation of other views.

(b) In addition to the currently shown views (1) a temporal outline (2) can be shown to support temporal navigation. Semantically related contents (3) are proposed to support search for contents.

Fig. 5. Examples for automatic adaptation to support typical user tasks.

  - Showing the semantic network and allowing interactive exploration (see Figure 4).
- *Search for related content* is supported by automatically:
  - Applying highlights to currently shown contents (see Figure 5(a)).
  - Recommending semantically related content from the audience or other presenters (see Number 3 in Figure 5(b)).
- *Comparison of contents* is supported by an adaptation of the layout to show semantically linked contents side by side.

To provide the automatic support it is necessary to get a more detailed insight about the situation and the tasks of the users. This requires to reason about the state and behavior of the users in the context of the current situation. Most actions and states are not observable directly, for example the SMR provides no sensor to distinguish between search and comparison behavior. Therefore, we need to estimate the state and actions from all available observations. The observations are noisy and user behavior may *likely* belong to a particular state. Our approach is to build a probabilistic human behavior model that reflects the states, actions, and observations. Using a Bayesian filter suited for such models, which relates observations to the situation, we can infer the current tasks of the users. As is typical for probabilistic inference, each task is associated with some probability. Our support will only be executed automatically if the task can be recognized with sufficient certainty (i. e. with probability larger than some user-defined threshold). A detailed description of our inference algorithm is provided in [21].

7 Implementation

We implemented the presentation tool “multipresenter"[1] which incorporates our solutions. Figure 6 shows its components and integration into the setup of our SMR (see

[1] A video that demonstrates the multipresenter is available at `http://youtu.be/A7XQzq4zavk`.

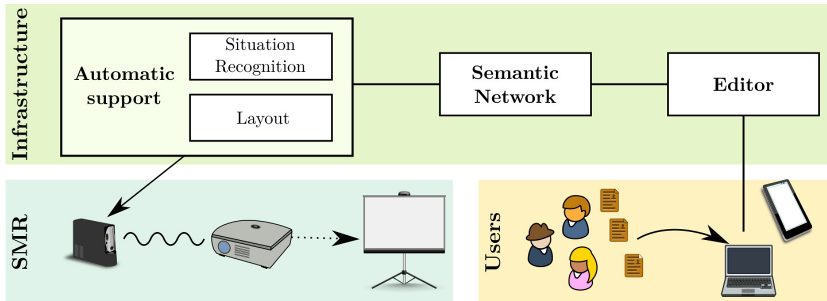

Fig. 6. Overview of the complete infrastructure and its integration into our Smart Meeting Room (SMR).

Section 3). The editor runs on the mobile devices and allows users to share their contents and provide semantic networks. Each instance of the editor connects to the infrastructure of the SMR and is automatically integrated into its middleware [18]. When users provide contents and semantic information via the editor, the data is transmitted by the middleware using network communication. In this way, all components in the middleware (i. e. editor instances on other mobile devices or the support components) can access these data. The layout component takes the user-provided constraints and automatically generates a suitable content distribution and layouts for the displays. Based on these generated layouts, contents are distributed to the miniature PCs of the SMR and displayed by the connected projector. The situation recognition considers the sensor data (e. g., from the positions of the users) to infer the current situation. If it is confident about a certain situation, it may adapt the display of contents (e. g., by changing the layout generation) in order to support the users in their current task.

8 Conclusion

In this paper we presented an approach that makes use of the advanced capabilities of a SMR. It allows an easy interactive configuration of a multi-display environment and further supports users with automatic generated view layouts. By using intention recognition, we can infer the tasks of the users and apply customized assistance. In this way, we address the challenges *C1*-*C4* of display ecologies.
We have tested our approach in two settings. First, we applied it to a discussion scenario on the impact of climate change [20]. Second, we used our system in a teaching scenario, which was part of a project at our university to improve learning and teaching conditions. In both cases we got positive feedback from domain experts as well as from non-technical experts, which found our tool “very helpful” and “easy to use".

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