Designing Multi-User Multi-Device Systems - An Architecture for Multi-Browsing Applications

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ABSTRACT

As users get accustomed to an increasing diverse range of mobile devices, personal computers, intelligent home and office appliances, as well as shared public devices, collaborative multi-device systems are emerging to benefit from using together devices of different users and different capabilities. This paper presents a conceptual framework for the systematic design of such systems in symbiotic environments. It distinguishes between information and interaction spaces. Focusing on using devices together, we introduce relationships between interaction spaces and annotatable mappings between the information space and the interaction spaces. Customizable annotations and the corresponding transformation of information support the development of collaborative systems for different scenarios. To demonstrate the validity of our framework, we introduce an architecture for multi-device web-browsing systems, and an annotation vocabulary which particularly focuses on symbiotic environments. The evaluation of our implemented prototype confirms the usefulness of multi-browsing, and the need for supporting both developers and end users to individually annotate web pages.

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces—*Prototyping*

General Terms

Design, Human Factors

Keywords

Collaborative multi-device web browsing, framework, annotation, collaboration, interaction metaphor

1. INTRODUCTION

In the era of ubiquitous and mobile computing, people are surrounded with and getting used to an increasingly diverse array of electronic devices. They range from personal mobile devices such as cell phones, PDAs and laptops, shared home and office appliances like televisions, loudspeakers, desktop computers and servers to shared public displays and information terminals. Each device is specialized for one or multiple usage scenarios, and differs significantly from each other in its computing, networking and I/O capabilities. Borrowing survival mechanisms from biology, *symbiotic environments* suggest using devices of different specializations and capabilities together to overcome the limitations of single ones. In such a device ensemble individual ones benefit from their relationship to each other [15, 16]. Apart from complementing the functionalities of multiple devices, using them together facilitates the information sharing within groups and communities or with the public.

Despite lots of previous research work on collaborative, multi-device applications, there is a lack of systematic methods and tools for the design of collaborative, multi-device systems. Furthermore, most existing frameworks demonstrate their feasibility with one or several specially designed scenarios. Either significant redesign of the framework is necessary to apply it to another scenario, or it is difficult to evaluate whether a framework is appropriate to support another scenario. In this paper, we propose a conceptual framework aiming at providing a systematic design of collaborative, multi-device systems in symbiotic environments.

The web has revolutionized the application development in the last few years. Traditional desktop applications (e.g. image or word processing, and map applications) are being developed for the web. Hence, we focus on multi-device web-browsing (which is referred to as "multi-browsing systems" for short) applications. We introduce an architecture which can be used to develop multi-browsing applications supporting different scenarios.

The remainder of this paper is structured as follows. Section 2 introduces a scenario of multi-browsing. Although we do not intend to develop just another system for another scenario, this scenario helps to explain our concept. In section 3 we propose our conceptual framework. Then we introduce our architecture for multi-browsing systems in section 4. Section 5 reports the evaluation results of our implemented prototype. We compare our work with related work in section 6, followed by a summary and discussions of potential future work in section 7.

2. SCENARIO

A group of friends spends the weekend in Vienna. On his way, Michael is searching for evening events (e.g. movies, concerts or parties) with his PDA. Standing in front of an internet-enabled public information terminal, the search result - a list of concerts - is shown on his PDA. The map showing the locations of the concert halls is displayed on the large screen of the terminal. Michael uses his PDA as a remote control to browse through the search results which are displayed on the information terminal. Michael's friends John and Tom have joined him. In order to evaluate the potential events to attend in parallel, Michael moves the event list to the PDAs of John and Tom. After a while the friends move the description of their favoured events to the screen of the terminal. They jointly make a decision, and Michael volunteers to book concert tickets for all. The login page of his bank is displayed on Michael's PDA, since his private, sensitive information is involved.

After the concert, Michael and his friends revisit the concert description on the web page. Together, they record a short review as an audio stream and select a few pictures they have taken during the concert. Finally Michael uploads the content and the web application recognizes both the audio stream and pictures as new variants of the concert description in different modalities.

3. CONCEPTUAL FRAMEWORK

We are inspired by the conceptual framework for designing and analyzing urban pervasive systems by Kostakos et al. [12]. We adopt their concept of space as a key design element, and distinguish between *information spaces* and *interaction spaces*:

- An *information space* conveys pieces of information which are available in the current environment.
- An *interaction space* is the volume within which a device or artefact effectively supports a human activity. For example, it allows a user to access information.

The link from the information space to the interaction spaces is the *display* relationship, i.e. one or multiple devices in the interaction spaces are utilized to display the information. In a symbiotic environment, the challenging task is to find the appropriate mapping between the pieces of information and the interaction spaces (see figure 2 and section 3.2). When using devices together, a web page can be split into multiple sub-pages, each of which is dedicated to one or multiple devices in the symbiotic ensemble. For example, the public part of the web page will be allocated to a public information terminal, while the private or the interactive part (e.g. a list of hyperlinks) will be allocated to a private handheld serving as a remote control. Additionally, one can imagine that certain information can be repeated on several devices, while its presentation (e.g. the modality) can differ. The mapping is scenario-specific. In the following, we show how the spectrum of publicness as introduced in [12] and the CARE properties [3] can be used to relate the information and interaction spaces.

3.1 Publicness

The spectrum of publicness is divided into three regions [12]:

- *Private* denotes that one person is in control or has access. It defines the highest privacy level.
- *Social* denotes that a group of people has access and that this group can prevent others from obtaining access.
- *Public* implies that no single person is in charge of or controls access. It defines the lowest privacy level.

Applying the spectrum of publicness to the spaces yields different classes of spaces (figure 1). For example, a private PDA creates a private interaction space, while a shared public display creates a public interaction space. However, a publicly installed ATM provides a private interaction space allowing a single user to access his/her bank balance. The kind of interaction supported by an interaction space (instead of its location and ownership) is decisive for the privacy level.

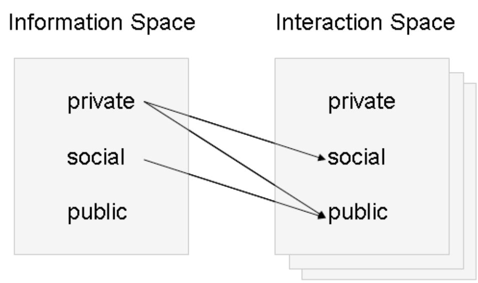

Figure 1: Using privacy categories to relate the spaces

Whenever people use social or public interaction spaces to access private information, or use public interactions space to access social information, privacy will be violated. The arrows in figure 1 which point to lower right show these situations.

In mobile environments, people join (possibly introducing new pieces of information and devices) or leave the scenario at any time. When they move, they may find themselves surrounded by different people and different devices in the proximity. Therefore, we extend the framework in [12] by allowing the dynamic integration of new interaction spaces, and considering the relationship between the interaction spaces.

In our scenario, John brought his PDA and joined Michael. The private interaction space offered by John's PDA is to be considered as *external* with regard to the private interaction space of Michael. Carelessly moving private information from Michael's PDA to John's PDA violates Michael's privacy. Since both interaction spaces have the same privacy level, the framework in [12] which considers the interaction spaces in an isolated way can not detect this privacy violation. In contrast, if Michael brings his own laptop to use it together with his PDA, the new private interaction space will be considered as *internal*.

In real life, the boundaries between private, social and public are neither rigid nor fixed. People fluidly shift their artefacts from personal to public and the many shades in between [8]. A software system shall allow people to dynamically adapt the privacy levels.

3.2 CARE properties

When using devices together, a part of a web page can either be displayed on exactly one device or repeated on multiple devices. We use the CARE (Complementary, Assignment, Redundancy, and Equivalence) properties to map an information space with a composition of interaction spaces. Originally, the CARE properties have been introduced to map a piece of information to a set of modalities [3].

- Redundancy and complementarity: When repeating a piece of information on several devices, it can be displayed using either equal (case R for redundancy in figure 2) or alternative (case C for complementarity) presentations. For example, a static map can be provided for mobiles in parallel to

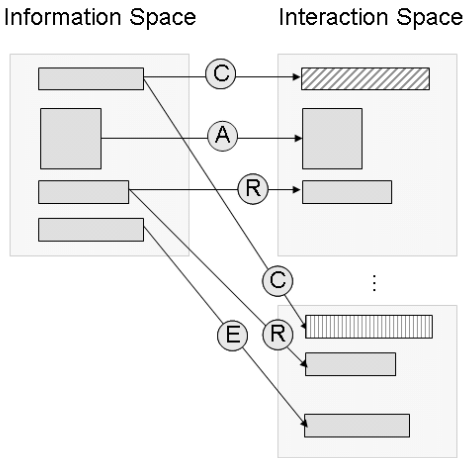

Figure 2: Using CARE properties to relate the spaces

JavaScript-enabled maps, or voice output serves as an alternative to textual output for multi-modal web pages [1, 17].

- Equivalence and assignment: When selecting a device in an ensemble to display a piece of information, the semantic of the information as well as the hardware and software requirements for the devices to properly render the information must be taken into account. A piece of information must be assigned to a certain device (case A for assignment in figure 2), since others in the ensemble don't fulfill these requirements, or all the devices in the ensemble offer equivalent choices for the rendering (case E for equivalence in figure 2).

Obviously, different scenarios have different CARE properties. Additionally, user studies (see section 5) have shown that people have different preferences for the CARE properties. Thus, in order to support different scenarios, a multi-browsing system shall allow people to individually assign CARE properties.

4. ARCHITECTURE

Our architecture for multi-browsing applications is shown in figure 3. The *multi-browsing engine* acts as a proxy lying between the web browsers of multiple devices and the web server. In order to use the multi-browsing functionality, a web browser must be configured to use this proxy. The proxy forwards a browser request to the web server (step 1 and 2), intercepts the fetched response (step 3), and returns a multi-browsing enabled web page to the user (step 4). In the current implementation, the proxy dynamically injects JavaScript files into the web page fetched from the web server. On the one hand, the JavaScript files insert a new toolbar (see figure 4) to support annotation, collaboration and registration of users and their devices. On the other hand they interact with the components of the multi-browsing engine. The architecture is flexible to support different deployment scenarios. Either the operator of a web site can place the multi-browsing engine in front of a web server in order to redirect all incoming traffic, or an independent third party can run the engine to allow for multi-browsing of arbitrary web pages.

Four databases are contained within the multi-browsing engine which are used to persistently store (1) annotation files of the annotated web pages, (2) user created content, (3) profiles of registered

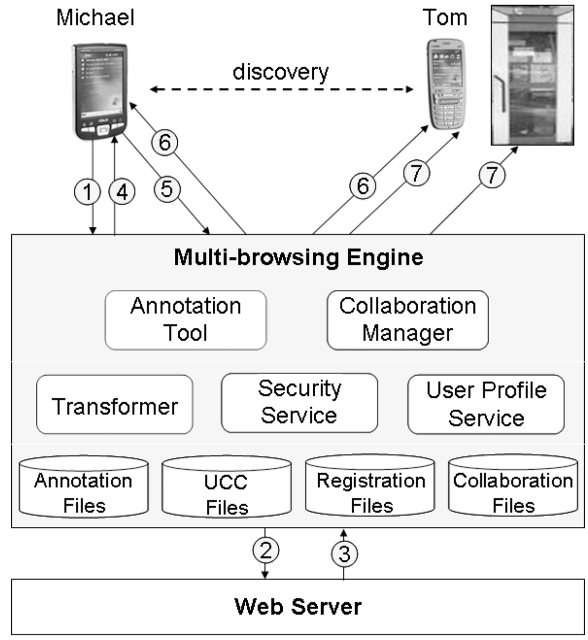

Figure 3: Architecture

users (e.g. their preferences) and devices, and (4) status of ongoing collaborations respectively.

The components *annotation tool* and *collaboration manager* will be described in detail in section 4.1 and section 4.2 respectively. In the following, we use the scenario in section 2 to explain the workflow among the collaboration manager and the underlying service components (i.e. *transformer*, *security service* and *user profile service*) to serve a collaboration request.

Figure 4: Screenshot of the annotation environment

Whenever Michael submits a collaboration request, for example, to move the web page on his device to Tom's device or the public display (step 5), the request is forwarded to the collaboration manager component which utilizes the security service and the transformer to process the request.

The security service component is responsible for identifying and warning the users of potential privacy violations. It retrieves the privacy categories of information spaces from the annotation files, and the privacy categories of interaction spaces from the registration files. In case the privacy category of an interaction space or the relationship between the interaction spaces (i.e. internal or external) are unknown, the security service interacts with the user by initiating, for example, a dialog “Is it[1] your private device?”. Displaying information on a device consumes its I/O resources. Hence, when moving web content to a non-public device, its owner must grant the access. The security service explicitly asks for permission by initiating a dialog such as “Do you want to accept a collaboration request from Michael?” with Tom (step 6).

The transformer component is responsible for adapting the web page for Tom’s mobile, or to split the web page and distribute parts of it to the public display. When splitting a web page, the transformer decides *where* to place a certain content. For example, it avoids placing private annotated content to a public interaction space. However, in case the option “Split” is disabled (see section 4.2), the user alone has already made the decision *where* to place the content. If a part of the information is of private category, its movement to any target device not owned by the requesting user will potentially reveal a secret. The transformer warns by initiating the dialog “This may disclose your private information. Do you want to proceed?”. In this way the user has got the opportunity to dynamically adapt the privacy level of his/her information. Finally, the transformer sends the transformed web page to Tom’s mobile or to the public display (step 7).

For the adaptation the transformer also queries the user profile service for Tom’s preferences. For example, Tom prefers the audio instead of the visual modality. The transformer retrieves the annotation file to determine whether a piece of information exists in alternative representations and their locations. For instance, the desired information in an audio format could be in the database of the user created content.

4.1 Annotation

When a web page or a part of it is to be moved to a target device, its representation may need to be adapted depending on the difference between the source and the target devices. Semantic information about the web content such as the grouping of correlated pieces of information and their ordering is essential for the adaptation task. Heuristics which exploit the structure of HTML pages to extract semantic information are often unreliable or insufficient. Thus, annotating web-pages is a common practice to provide additional semantic information [1, 10, 18, 14, 6]. Annotations and heuristics are complementary to each other, since it can not be assumed that every web-page is completely annotated.

4.1.1 Annotation vocabulary

To our knowledge, there is no broadly agreed annotation vocabulary for web pages. Moreover, most research work focuses on adapting web pages to small-screen devices [7, 4]. Often it has been overlooked that web pages can be adapted to large-screen devices. For example, when utilizing a public display, images and maps of a better quality can be provided. Annotations can be used to indicate that certain pieces of information exist as several alternatives. We are not aware of annotation vocabularies which specially focus on symbiotic environments.

Most existing annotation frameworks target only web application developers because either their expert knowledge is required or the annotation task needs to be performed at design time. As illustrated by our scenario, allowing users to individually assign (and even dynamically change) privacy categories and preferred CARE properties is crucial in symbiotic environments. Therefore, we support annotations by both developers and users at design time as well as runtime. We divide the annotation vocabulary into two main categories:

- Semantic structure of the information space: Most existing web pages are rendered using solely HTML structures which lack the capability of describing the semantic structure of a web page such as the atomicity, grouping, and ordering of information. Annotations of this category provide information about the semantic structure of a web page. They primarily describe the information space.
- Mapping between information and interaction spaces: Annotations of this category consider the relationship between the spaces in order to render the information space on a set of collaborating interaction spaces. Examples are the privacy categories, CARE properties for content distribution, priority and alternative presentations of information. Alternatives (e.g. the same content presented in different modalities) can be created both by the developers and users. In the latter case the alternative information belongs to “user created content” emphasizing content created by non-expert users at runtime.

Type	Vocabulary
Content Distribution	Complementary, Redundant, Assigned (Local, Remote), Equal
Priority	Desktop, PDA, Mobile
Privacy	Public, Social, Private
Alternatives	Add Content, Modify Content, Delete Content

Table 1: Annotation Vocabulary

Table 1 lists our current annotation vocabulary. We use device categories to describe the priority categories of information. The higher the required device category (for example, desktop) to display the information, the lower the priority of the information. Hence, a piece of information of the priority category “mobile” has the highest priority and will be displayed on any, even tiny devices.

We are aware of the fact that it is nontrivial to develop an annotation vocabulary which is easily understandable by different target groups. We have conducted user studies to evaluate our annotation vocabulary (see section 5).

4.1.2 Annotation environment

We have developed our annotation environment to achieve the following goals:

- The annotation environment shall be well integrated into existing web pages without altering their general appearance: It is integrated into the dynamically injected toolbar (see figure 4).
- The annotations shall be separated from the web page’s original source code: The multi-browsing engine stores annotations and user generated content externally to the web pages

[1]It refers to the target device which is Tom’s mobile.

in separate annotation files which are persistently kept in a database. The current implementation uses XPath [19] to map the annotations to the associated elements in the original web page.

- The annotation environment shall provide visual feedback to the annotators: When the annotation mode is activated, elements of the web page are being highlighted by hovering over them using the mouse cursor. In order to annotate a certain element, a context menu is provided which shows the available annotation vocabulary (see figure 4). Inserted annotations are represented inline using icons according to its category and the modality of the inserted content respectively. Existing annotations can be modified and deleted as well. Note that a user is only allowed to modify or delete his own annotations.

4.2 Collaboration

The collaboration environment is part of the dynamically injected toolbar (see figure 5). It provides a *Multi-Browsing* menu to facilitate collaboration requests, and a *Collaborations* menu to manage collaborations.

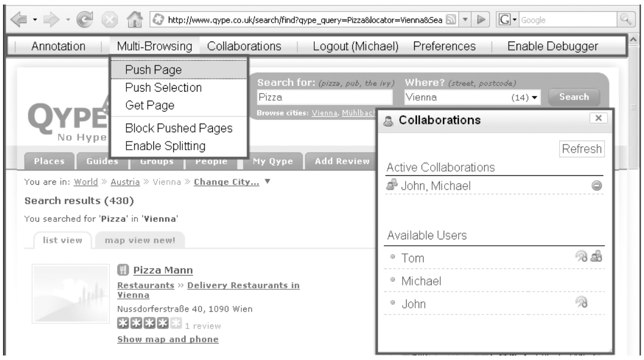

Figure 5: Screenshot of the collaboration environment

The *Collaborations* menu allows users to (1) create new and remove existing collaborations and to (2) invite other users to existing collaborations. The menu in figure 5 shows an active, ongoing collaboration between Michael and John. There are two plus buttons beside Tom. With the left plus button, Michael can create a new collaboration together with Tom. With the right button, Michael can ask Tom to join the currently active collaboration with John. Whenever interaction spaces are to be composed, members in the ongoing collaboration need to permit the inclusion of new interaction spaces and decide on the relationship between the new and existing interaction spaces. Whenever an interaction space has been invited to a collaboration, the *collaboration manager* component of the architecture also asks its owner if he/she wants to join.

It is possible to push only a selected part of a web page. The option "Split" specifies whether the web page can be split, adapted and distributed to the participating devices. A user has the choice to grant (i.e. *accept pushed pages*) or deny access (i.e. *block pushed pages*) to the display of his/her device at any time.

5. EVALUATION

We have implemented a prototype of the multi-browsing architecture and evaluated it with 14 participants. At the time of conducting the user-study, the annotation environment has been fully implemented. All other components of the architecture (cf. figure 3) were rudimentarily implemented. In particular, the transformer solely relied on the annotations to perform adaptation and content distribution.

With this user study we intended to get the following hypotheses confirmed or questions answered:

- *Our framework supports the inherent mobility of users in a symbiotic environment*. As a consequence to this hypothesis, we think that collaborative browsing enhances the browsing experience in smart environments.

- *Different people prefer different ways of displaying information in symbiotic environments*. This hypothesis is motivated by various discussions, and especially different opinions we had on semantically meaningful and visually appealing web page distributions. Hence, it is important to provide an annotation environment which allows both, developers and end users to annotate web-pages individually.

- *Is the proposed annotation vocabulary understandable? Should further annotations be added to the vocabulary?* A vocabulary too complex to understand cannot be applied by ordinary end-users. We wanted to ensure a flat learning curve.

- *The original web-page presentation is neither altered significantly by the injected environments nor by applied annotations*.

Among the participants, there are 3 experienced web developers, 7 software developers who are however not familiar with web programming technologies, and 4 ordinary end users who frequently browse the web. The participants were given an overview of the features of collaborative multi-browsing and of the annotation vocabulary.

The storyline for their tasks is based upon the scenario in section 2. Michael has viewed the description of a pizzeria on Qype[2] and of a DVD about Indiana Jones on Amazon[3] on his PDA. He would like to push the descriptions to the information terminal in order to make the decision with Tom together. We asked the participants to take over the role of Michael. In the first place, they were asked to decide which parts of the web-sites were relevant in order to be able to make a decision together with Tom. This implies that the participants were required to reflect on the structure of the presented information, as well as on how to display it. Next, the participants used the annotation environment to annotate both web-pages, focusing on their preliminary considerations. Afterwards, the participants filled out a questionnaire with 21 questions or statements respectively. Each question and statement had to be graded with grades from 1 (meaning *"very good"* or *"I totally agree"*) to 5 (representing *"deficient"* or *"I totally disagree"*). The questionnaire was subdivided into three different main categories regarding the collaboration browsing as a feature, the implemented annotation environment and general feedback.

- *Collaboration browsing:* This category included statements like for example "It is useful to collaboratively browse a

[2] http://www.qype.co.uk/place/26058-Il-Sestante-Wien
[3] http://www.amazon.de/Indiana-Jones-Trilogie-Steelbook-Harrison/dp/B0015Q5GKW/ref=sr_1_1?ie=UTF8&s=dvd&qid=1212564902&sr=8-1

web page", "It is useful to move only certain parts of a web page to different devices" or "Collaborative web browsing enhances my browsing experience".

- *Annotation environment:* Questions in this category focused on both the usability of the annotation environment and users' understanding of the annotation vocabulary. Statements and questions in this category were for example "The annotation environment integrates well with each web page", "Working with the annotation environment was intuitive", "The available annotations are clear to me and I understand their meanings", "The available annotations are detailed enough. They do not need to be more specialized" or "The graphical representation of the annotations can be easily understood".
- *General feedback:* Statements of more general nature were "The implemented features are useful in general" or "I will use the environment if it is available".

In the following we present some results from the evaluation. 10 out of 14 participants find it useful to collaboratively browse a web page, whereas 13 prefer to move only certain selected parts of a web page. 12 believe that collaborative web browsing enhances their browsing experience.

A total of 8 participants find the annotation environment intuitive to work with. 10 participants find the annotation vocabulary understandable, whereas 7 think that the graphical representation of the annotations can be easily understood. 9 participants confirm that the available annotations are detailed enough. The main problem with the vocabulary lies in the meaning of the CARE properties and the wrong assumption that an assignment to a local device implies a certain privacy category. The participants have finished the annotation task for the second page more quickly than for the first page. They inserted comparably more annotations to the second page than to the first one. This confirms that the annotation environment is easy to learn. Moreover, 9 participants state that it integrates well with existing web pages.

As an end user, 8 participants would like to use the annotation environment more often in order to adapt web pages to their needs. As a developer, 9 would like to use it more often to provide more tailored web pages.

Additionally, we compared the annotation files of the participants regarding the number and granularity of annotations they inserted, and the focus of both the annotated content and the utilized vocabulary. This comparison showed significant differences among the participants. The majority of the annotations focus on multimedia content, privacy-related content (e.g. "Add to Shopping List" on Amazon) and hyperlinks. However, hyperlinks have been differently annotated. Some participants want to keep the hyperlinks on their handhelds using them as remote controllers, while others want to display them on the shared display to facilitate collaboration (i.e. jointly decide to follow the links). It is interesting to see that web developers have primarily used the privacy and the priority category, while non-experts have focused on the CARE properties. The reason for this phenomenon remains to be investigated.

Regarding the implementation, a tighter link between the annotation icon and the annotated content is wished. Whenever the cursor moves over an annotation icon, the associated annotated content shall be highlighted. Moreover, a preview of adaptation and distribution results will be appreciated which provides feedback about whether the annotation vocabulary has been correctly understood, and the intended results have been achieved.

6. RELATED WORK

Our conceptual framework adopts the concept of interaction and information spaces, and the spectrum of publicness from the framework by Kostakos et al. [12]. With our particular focus on using devices *together* we extended their framework by introducing relationships between interaction spaces and the CARE properties to relate an information with a composition of interaction spaces, These extensions allow our framework to detect privacy violations which can not be identified by the original framework, and to better take the advantages of individual devices.

Multibrowsing is a system which allows moving web pages among multiple displays [11]. Its main drawback is the lack of distinction between private and public artefacts, although both public and private displays have been explicitly mentioned. Additionally, there is no concept to adapt the web pages in order to take the different capabilities and constraints of the devices into account. Web pages can only be completely moved from one device to another.

WebSplitter [9] splits a web page among multiple devices of multiple users. Additionally, WebSplitter enables the presentation of different partial views of the web page to different users. A separate annotation file defines the rules for the splitting. For instance, the rules define the following: users of a certain privilege group and equipped with devices of certain capabilities are allowed to view an enumerated set of XML tags of the web page. The annotation file also consists of information (e.g. passwords) to perform user authentication. In our opinion, the intermingling of different concerns (e.g. access control and adaptation) makes the annotation file complex, and inflexible.

The collaborative web browsing approach in [13] uses the handheld devices of multiple users together to browse web pages designed for desktop PCs. A web page is divided into multiple components, and each is distributed to a different device. The focus of this work is on page partitioning which is able to take different conditions such as user preferences or capabilities of each device (including resources and functionality to play video or audio content) into account.

UsaProxy [2] is a system for remote web collaboration between two users in different locations. In a shared browsing session both users have full control over their browsers. Both views seen by the users (in particular, also the mouse cursors) are synchronized.

The framework for coordinated multi-modal browsing in [5] differs from our approach by offloading the coordination among multiple devices to the client devices. Whenever a client in the ensemble initiates a HTTP request, it instructs other clients to issue the same request via messaging among the clients. A consolidating proxy is required to aggregate these requests.

7. CONCLUSION

We have presented our conceptual framework aiming at providing a systematic method for the design of collaborative multi-device applications in symbiotic environments. We distinguish between information spaces and interaction spaces, and support the dynamic integration of interaction spaces which is vital in mobile and ubiquitous environments. We apply the publicness property and the CARE properties to relate the information and interaction spaces in order to use the devices together. These properties are annotatable to support different scenarios.

Based on this framework, we presented an architecture for multi-browsing applications. It distinguishes from previous work by introducing the annotation component. Annotation plays a crucial role for the scenario-specific mapping between information and interaction spaces. We presented our annotation vocabulary and the annotation environment. The initial evaluation of our prototype implementation clearly shows the difference between annotations from different users for the same scenario. This confirms the need for annotation in order to support customized collaboration and collaboration for different scenarios.

When multiple users collaboratively browse a web site, new interaction metaphors will emerge. For instance, after evaluating the events in parallel, Michael and John move the descriptions of their favored events to a shared display. In the current implementation, the descriptions from the friends are shown sequentially in different tabs of the browser. It is imaginable to merge the descriptions into one list. New annotation vocabularies are necessary to specify this temporal relationship and new transformers are required to adapt the pages. As future work, we will investigate new interaction metaphors and develop the required annotation vocabulary and transformation component to support them.

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