CurationSpace: Cross-Device Content Curation Using Instrumental Interaction

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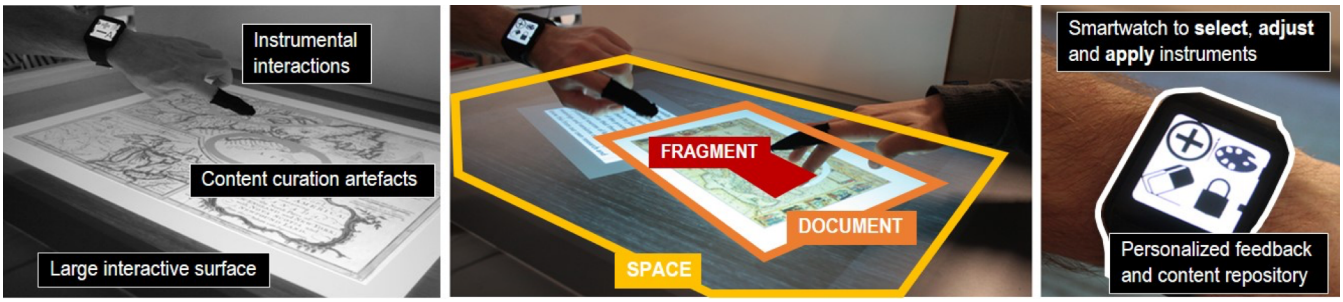

Figure 1. ***CurationSpace*** **provides a shared collaboration space for content curation based on instrumental interactions.**

ABSTRACT

For digital content curation of historical artefacts, curators collaboratively collect, analyze and edit documents, images, and other digital resources in order to display and share new representations of that information to an audience. Despite their increasing reliance on digital documents and tools, current technologies provide little support for these specific collaborative content curation activities. We introduce *CurationSpace* – a novel cross-device system – to provide more expressive tools for curating and composing digital historical artefacts. Based on the concept of Instrumental Interaction, *CurationSpace* allows users to interact with digital curation artefacts on shared interactive surfaces using personal smartwatches as selectors for *instruments* or *modifiers* (applied to either the whole curation space, individual documents, or fragments). We introduce a range of novel interaction techniques that allow individuals or groups of curators to more easily create, navigate and share resources during content curation. We report insights from our user study about people's use of instruments and modifiers for curation activities.

Author Keywords

Instrumental Interaction; Cross-Device Collaboration; Curation Work; Content Curation; Smartwatch Interaction

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

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INTRODUCTION

There are many different curation practices, extending beyond the more traditional interpretation of a professional museum curator. One of these practices is *content curation*, which can be defined as the process of *collecting, analyzing, displaying* and *sharing* information in order to derive new insights and knowledge and present these findings to a broader audience [33]. Curating content often requires *specialized knowledge* and *collaborative artefact discovery*. One example of such content curation is that of historical documents, often done by (non-professional) historic societies or charities who collaboratively create curated data sets, formulate conclusions, and create new representations. Over the years, technology has resulted in a growing amount of information, allowing for new ways of conducting curation processes. Moreover, it enables groups to work collaboratively, using the various resources, bringing together people with expertise from different backgrounds [40]. The focus of our research is on curation work for ad hoc collocated resource collation. Specifically, we explore how content curation tasks, such as collecting, organizing, reviewing, displaying and sharing digital content (e.g. images, maps or notes), can be supported effectively through using multiple tools and devices at hand for group work.

Curating digital content in a group setting, however, using *multiple* digital devices can be challenging because it requires a large amount of configuration work [16] when setting up devices and sharing resources. Furthermore, even though people use computationally powerful and interconnected devices, most of these devices are not designed to support in situ collaborative work [34]. Which devices might be put to good use in order to support ad hoc curation work? Large displays can be used for shared curation work in combination with other hand held technologies. These offer a high resolution interaction space and allow for collaboration and exploration of large datasets [2]. However, several problems arise from using large and public displays for content

curation, such as the positioning of control instruments on large screens [1, 39], territoriality [37], or privacy when working with private data [8]. The use of personal devices with large displays offers ways of overcoming these while also providing new methods for controlling and interacting with content. In particular, using a worn device with a tabletop allows users to personalize systems with their own content. Compared with using phones for personalized input with a larger interactive surface (e.g., [35]), the use of a smartwatch does not require to be held, leaving users' hands free for interactions.

CurationSpace was designed as a personalized sharing system that leverages the functionality of (i) an individual user's *smartwatch* for *instrumental interactions* [4] and (ii) a shared interaction space (e.g., a large, touch-enabled tabletop or wall display). It was motivated by how we interact with tools in the real world, in which there exists a many-to-many relation between tools (like pens, scissors, markers) and objects of interest (paper, plastic, fabric).

The smartwatch is used to identify its user, to store and share personal information, provide the user with customized views or interfaces, while also allowing protection of private and sensitive information which a user does not want to share publicly. It is a *mediator* between the user and the interaction space that supports collaborative working with a focus on content curation. The shared public space is a multi-touch surface that multiple users can interact with.

The contribution of this paper is a new instrumental interaction approach for collocated curation work that (i) separates space, domain object and individual fragments as interaction entities, and (ii) uses a smartwatch to augment human touch with configurable tools that act upon these entities.

INSTRUMENTAL INTERACTION FOR SMARTWATCHES

The vision behind ubiquitous computing and cross-device interactions is to allow users to seamlessly interact with digital information where and when needed. As Bødker [7] argues, users do not interact with technology but rather "*through the interface*". Computer devices, systems, and applications are mediating tools or instruments that allow users to act upon information using systems from their environment.

The notion of Instrumental Interaction was originally proposed by Beaudouin-Lafon [4] as a POST-WIMP interaction model in which there is a strong conceptual separation between the information, data or other domain objects, and the *instruments* or *tools* that are used to act upon those domain objects. Instruments are a combination of hardware and software components that mediate the interaction between the human and the domain objects that are of interest to the user. The user interacts with instruments that translate its actions to the underlying data and provide feedback to the user. This instrumental interaction model is inspired from the observation that "*our interaction with the physical world is governed by our use of tools*." [4]. Instrumental interaction is based on three design principles [5]: (i) reification, the process of objectifying instruments and interactions, (ii) polymorphism, the property that allows for a single instrument to be applied to any domain object, and (iii) reuse, the process of leveraging previous defined objects for future use.

This Instrumental Interaction model was extended by Klokmose et al. [22] into a Ubiquitous Instrumental Interaction model, in which instruments were made much more explicit in the form of reusable interchangeable artefacts that could be used on different types of domain models across different types of surfaces. Instruments can migrate from one device to another, from one data structure to another. Although instruments can break on certain types of domain objects, they should provide an operational consistency across domain objects and interactive surfaces. Klokmose et al. [22] did not differentiate between types of devices, but rather see instruments as hardware-independent digital constructs that themselves should be easy to manipulate by other instruments.

In this paper, we differentiate between types of devices, and more specifically their role towards supporting instruments. By wearing a watch, we can automatically identify users through their touch input and gestures, which can help autoselect instruments, and more generally *augment the human touch capabilities*. Rather than using physical instruments, the watch can be leveraged to contextually reshape the instruments executed by our hands, as well as our human touch. The watch can in this way be used to configure and execute the instruments that are applied to a range of different document types available in *CurationSpace.*

RELATED WORK

Wrist-based Interactions and Smartwatches

Previous research has shown that the wrist is a good place to position a device that needs to be accessed quickly or frequently [3]. DeskJockey [44] offloaded interface elements by projecting them onto its surroundings. Similarly, Mayer et al. [26] introduced user interface beaming, leveraging a smartwatch to interact with smart objects in the environment. Duet [10] extended the input space on a phone with a smartwatch, e.g. the smartwatch acts as a tool palette when editing input on the phone, and Expressy combined a wrist-worn IMU to expand the expressiveness of touch interactions [41]. In *CurationSpace* the smartwatch acts as tool selector, augmenting the user's touch, and can therefore be seen as an extension of the shared surface screen. It declutters the shared surface from menu items while, similar to Local Tools [6], allowing for quick access to the commonly used instruments.

Although researchers have explored using a smartwatch as a public display [28], a smartwatch is a personal, body-worn device, which is predominantly owned and operated by a single person. Reading personal notifications is the second most common usage of a smartwatch (after reading the time), and denotes overall the longest interaction time with a smartwatch [29]. Leveraging the one-user-per-device property, *CurationSpace* allows users to personalize input and bring

private content to a shared surface. GestureWrist [31] introduced hand and arm posture recognition on the wrist, Gesture Watch [20] detected gestures above and around a smartwatch, and Haptic Wristwatch [27] allowed users to perform gestures, such as covering the watch-face, or interact with the bevel of a wristwatch.

Sensemaking on Large Surfaces and Across Devices

Previous research has explored how a single user can work with large collections of digital data, for example, on large screens [2], tabletops [12] or using multiple devices [13]. While public displays offer a high resolution interaction space for collaboration [1], it was pointed out that territoriality [37] and privacy [8] have to be considered. Augmented Surfaces [32] introduced hybrid and collaborative digital/physical interaction space and UbiTable [38] explored the design space of tabletops when used in a kiosk-style walk-up-and-use scenario. Similarly, *CurationSpace* was developed for sharing and exploring digital content on a large interactive surface in walk-up-and-use collaborations.

Using a phone as an input device for large displays has been explored, e.g. in Touch & Interact [14] a phone could be used to interact with a display similar to a stylus on a PDA. Schmidt et al. built on this input vocabulary [36] and detected a phone's touch on a tabletop to, for example, allow data transfer or tool selection and extension of the input and output space [35].

Cross-device Interactions

Using mobile devices for cross-device sensemaking has been used for example by United Slates [9] and Conductor [13]. In more recent years researches have focused more and more on cross-device interaction with body worn devices, such as SleeD [43], Duet [10] and WatchConnect [17]. Schmidt et al. [35] explored the design space of mobile+surface interactions. A taxonomy for surface gestures, together with a user-defined gesture set was presented [42]. More recently, Webstrates [21] provides an environment for collaborative, real-time sharing and editing.

No prior work has explored how smartwatches can be used in conjunction with a shared space for collaborative content curation. *CurationSpace* introduces a collaborative document presentation system that allows users to modify its content through a number of instruments that can be selected, adjusted, and applied using a personal smartwatch. Leveraging the fact that smartwatches are body-worn and personal devices, *CurationSpace* allows users to bring personal content into a shared space, customizing their input using instruments selected on the watch. Further, the watch can provide personal feedback through its easily visible display, not occupying any space of the shared area. *CurationSpace* allows for touch input on the smartwatch as well as gesture input using the smartwatch's internal sensors.

SCENARIO DESCRIPTION

Our content creation scenario describes the process of groups **collecting**, **analyzing**, **displaying** and **sharing** information – for example historic documents – in order to present it to audiences in new ways [33]:

Lisa is interested in the history of the street on which she lives. She joined a volunteer-driven historic society that preserves the history of her street, through collecting, analyzing, and reworking various sources of historic material, including maps, photographs, and locals' memories. Lisa is working together with John on a report about the history of the local hospital. They split up their work to research different facets online, in local archives, libraries. In order to collaboratively organize and analyze their information, they meet in a library using the CurationSpace system.

Lisa and John connect their smartwatches to the system. John shows Lisa a chapter of the report he has been working on. Lisa edits the text and images of the section using various instruments. Lisa also extends her collection of photos of historic maps with the ones that John has found. They review and finish the editing on one of the chapters of their building report. After two hours of exploring and sharing, they have created a new visual history of the hospital, loaded their work onto their watches so that they can continue their work at a later stage and vacate CurationSpace.

Throughout this paper, we refer back to the key curation activities from this scenario.

CURATIONSPACE

The design of *CurationSpace* is inspired by the observations of how people collaborate and interact with *physical documents* during a group session [23]. First, people often organize the table into distinct *spaces* that serve several purposes (e.g. often the middle of the table is used to share or present content to each other, while the edges closer to the users are used to store personal notes or documents [37]). Second, to discuss and reflect on content, people often place documents (reports or collages that are composed of smaller fragments, such as images, photos, texts, maps or other relevant resources) onto the table, which also facilitates sharing of documents or fragments with others. Third, users utilize tools (e.g. pens, markers, tape, pencils, scissors) to modify, annotate and create content while interacting with the *documents* or *fragments*. Importantly, tools can be applied to different types of documents, e.g., a pen can be used to write new text, to annotate a map, or to sketch a new figure.

Inspired by Beaudouin-Lafon's ideas on Instrumental Interaction [4] and Kay's vision of dynamic media [18], *CurationSpace*'s design provides a new document presentation and interaction model that follows this clear separation between (i) the cross-device interaction *space* that is being used as part of the curation work, (ii) the *documents* that are shared in the space, (iii) the individual *fragments* that make up each document, and (iv) the *instruments* that people are using to modify and create content during the curation process (Figure 1 middle). We extend established interaction techniques [6, 10, 17, 36] to explore a system implementation of this vision for supporting content curation tasks on a

shared surface, using personal devices. *CurationSpace* uses smartwatches as instrument selection devices that enable people to reconfigure their hands into different tools needed to perform curation work. Based on the principles of Instrumental Interaction [5], *CurationSpace* is built around three main principles:

1. **Dynamic resources –** To allow for reification [5], information is structured within three levels of abstractions: documents, fragments and spaces. These atomic units of interaction are exchangeable, combinable and controllable to create high level information structures.
2. **Tool multiplicity –** A basic set of tools are provided that can be applied to any resource. Tools or instruments can be applied to a variety of dynamic media, allowing for polymorphism across objects types and reuse of the same tool across a suite of information resources [5].
3. **Personal and shared objects –** Tools and objects can be personal or shared with other people. Both the hierarchical resource structure as well as the tool multiplicity are constrained by user roles and access models.

CurationSpace components

CurationSpace consists of two components: a smartwatch application and a touch-enabled large interactive surface. The smartwatch allows users to select instruments ("interaction instruments" in Instrumental Interaction [4]), which they can apply to documents on shared spaces to change their properties. Each instrument acts on a multitude of different documents and fragments, but to the user it only appears as a single instrument (e.g. "colorize", "delete", or "create"). On the surface side (Figure 1 left and middle), *CurationSpace* consists of three nested modules. These represent the domain objects of instrumental interaction. At the broadest level, there is an *interaction space* which is shared among all users and spans one or multiple interactive surfaces. Using *instruments*, a user creates or interacts with *documents*. Each document is owned by a user; however, they can share access to a document. Each document in return can contain one or multiple *fragments*, e.g. text, images, or a canvas.

The smartwatch (Figure 1 right) acts as a *mediator* between the user, the interaction space and the objects within, by providing a variety of instruments. Since every smartwatch is owned and worn by one individual person, they can be used to personalize the input, provide access to personal data, and allow for personal feedback. Using a smartwatch as an instrument selector reduces the need for cumbersome menu selection on the shared surface, allows for hands-free interaction and does not occupy space on shared surface.

General interaction with CurationSpace

CurationSpace starts with an empty interaction space. A user interacts with the space by applying instruments. For example, touching the interaction space will automatically use the *create instrument* to produce an empty rectangular shaped document. Documents can be resized and repositioned. Each document is either private or public, defining who can interact with it and blocking access to unauthorized users. Authenticated users (the *owner*) can manipulate their own documents using multi-touch gestures on the surface, which are defined by the selected instrument on the smartwatch. A private document can be made public (shared) by the authenticated user using the *share instrument*, allowing everyone to interact with it. One or multiple fragments can be added to each document. Fragments contain either text, images, or a canvas and can also be manipulated using instruments. When interacting with their own document, the user's smartwatch lights up in a matching color to indicate the connection. The watch also shows the currently selected instrument.

Instrument selection may occur automatically, based on the current context, or manually through explicit user selection. The user interacts with the shared space using the selected instrument. An instrument can be deselected either implicitly by selecting a new instrument, or explicitly by tilting the smartwatch. The functionality of some instruments is contextual, based on the type of domain object with which the user is interacting. This contextual difference lies in the nature of instrumental interaction and the system has to mediate [22]. This mediation is integrated into our system's underlying architecture: domain objects "understand" how to react to the application of instruments (through an event model) and therefore mediate the instruments' effect on them. The connection with the shared space can be broken by covering the smartwatch. This results in all documents being removed from the space and offloaded to the smartwatch.

Technical implementation of CurationSpace

CurationSpace is implemented on a modified Microsoft Surface 1.0 SP1 tabletop running Windows 7. The system runs a distributed message and content server based on SignalR that connects the watches (and potentially other devices) to the surface application. We used a Sony SWR50 SmartWatch 3, running Android Wear, connected to an Android smartphone via Bluetooth connection. The phone acts as a proxy between the smartwatch and the tabletop, allowing for a network connection between tabletop and smartwatch. The smartwatch transmits sensor data, instruments, and content selection to the tabletop, and receives system status updates.

A touch on the surface is considered *authenticated*, when it can be associated with a particular user. In our setup, a user wears a glove with fiducial markers attached to the finger (similar to [25]). Since each smartwatch belongs to an individual person, it can provide the fiducial marker IDs of its user to the system, therefore identifying the user to the system. It also acts as a private content repository, allowing a user to bring in their own data. The smartwatch has touch input, and its integrated IMU can be used for gesture recognition (e.g. the user disconnects from the system by covering the light sensor of the watch; or performs a tilt gesture to deselect the selected instrument). Further, it extends the shared surface to provide personalized, private feedback. Available instruments are shown in a grid-layout (Figure 1, right) and content in a scrollable list (Fig. 3, top) on the watch's screen.

CurationSpace represents the core ideas of Instrumental Interaction in its underlying distributed system architecture, in which instruments are *object events* that can be triggered on domain objects. It is not the instrument that defines its effect, but the domain object that reacts to the event of instrument-application. Introducing new instruments means simply introducing a new object event, implementing the receiver on the domain objects and its reaction to the event. If no event listener is implemented, the domain object will simply ignore the application of that instrument. Instrument mediation and instruments' many-to-many relation with objects is therefore integrated into our system's architecture: domain objects "understand" how to react to the application of instruments (object events) and therefore mediate how to react to an instrument's application. Furthermore, when no tool is selected, some domain objects trigger automatic tool selection upon a user's touch, e.g., when no tool is selected and the user touches the interaction space, the "create" instrument will be automatically selected.

CurationSpace instruments

Instruments customize users' touch input, which extends it beyond the normal binary touch. As laid out in the instrumental interaction model [4], the conceptual separation between domain objects (documents in *CurationSpace*) and instruments frees instruments to be reusable artefacts which can be applied on different domain models. While one instrument's usage is consistent across domain objects, the underlying interpretation on the data depends on the domain object. Differing from the work by Klokmose et al. [22], *CurationSpace does* employ device boundaries, differentiating between each user's smartwatch and the shared spaces. We argue that using the watch as an explicit instrument selector allows the differentiation between an individual's instrument and work, and thus allows group collaboration on a shared interaction space. Each user's smartwatch serves as an instrument selector and a personal identifier, receives personal system feedback, and provides a personal content repository. Using and adapting these instruments allows users to contextually re-configure and augment touch input.

Our set of instruments is informed by the key curation tasks of our user scenario. Depending on the current system state the instrument is being applied to, these affect and alter the domain objects in different ways.

- **Create instrument:** Allows users to create documents and fragments. The watch acts as an identifier and holds users' personal data to be shared with the space. This instrument is the default instrument when interacting with the space itself while no other instrument is selected.
- **Manipulate instrument:** Selecting an object or fragment allows the user to change its position, rotation, size, and to crop it using multi-finger gestures. The smartwatch acts as an identifier and tool selector for further operations. This instrument is the default instrument when interacting with a document or fragment while no instrument is selected.
- **Color instrument:** Using the smartwatch a user can select a color on their smartwatch. The color instrument can be applied to different domain object, e.g. it can be used to draw on a canvas, highlight parts of an image or color text.
- **Increase / decrease instrument:** These instruments allow the user to zoom in on a picture, increase the font size of a text, or show a document in full screen mode or vice versa.
- **Erase instrument:** The erase instrument acts as an eraser on a canvas, can be used to delete text through selection, remove images by touching them inside a document, or eradicate an entire document from the space.
- **Copy instrument:** This instrument allows the user to duplicate a document or image fragment, or to copy and paste text through selection.
- **Share instrument:** Created documents are owned by one user. Sharing a document allows other users to manipulate the documents.

These instruments should be seen as an example list of tools demonstrating the concepts of using Instrumental Interaction for content curation tasks, rather than an exhaustive set.

INTERACTION TECHNIQUES FOR CURATION TASKS

In the following we illustrate how these atomic instruments support collaborative content curation, by using the smartwatch for instrument selection, feedback display, and personal content repository. We illustrate the nuances of these techniques with our scenario application.

Figure 2. Using the implicitly selected *create instrument* (left) a user creates a new document on the interaction space (right). A green marker shows the authenticated interaction (middle).

Creating documents and adding content into fragments

Creating new documents for arranging curation content is one of the key content curation tasks. We designed instrumental interaction smartwatch techniques to facilitate the ad hoc creation of documents and adding content directly in context: *John wants to share photos of historic maps he has found in the archives. To start, he touches an empty area on the interaction space. After a 1.5 second dwelling time (to prevent accidental document-creation) a new document is created (Figure 2). The system selects this function automatically because on the empty interaction space no other instrument than the create instrument has an effect. After creating a new document, John wants to add pictures. He explicitly selects the create instrument on his watch, which then presents him with thumbnails of the content he can share from the watch (Figure 3 small inlay top). He can cycle through the text and images through touch gestures, and select the desired image of the map, adding it as a new image fragment to the document. The content is added the document he last activated through interacting (touch or move) with it.*

Figure 3 shows a screenshot of interaction space containing five documents, of which two are docked to the side. Two documents are owned by John (green border), two by Lisa (purple border), and one has been shared publicly, allowing everyone to access it (white border). *CurationSpace* supports different document types. Currently implemented are text (Figure 3, middle right), images (Figure 3, middle left), and canvas (Figure 3, bottom right). Documents' borders are marked in their owner's color (here: green and purple; white borders indicate public access), and can be docked to the size to declutter the interaction space (Figure 3, bottom).

Figure 3. The smartwatch acts as a personal content repository (inlay top), allowing users to share their personal data.

Manipulate and organize documents and fragments

When sorting through documents, people employ the space around them [2]. Using the document system, *CurationSpace* allows users to spatially arrange their content. The manipulate instrument is the default instrument when interacting with documents while no other instrument is selected, and can be used to position, resize, and rotate documents. For better overview, documents can be docked to the sides of the display, shrinking them to small preview icons (Figure 3), or enlarged to take up the whole screen. This allows for a large number of documents to be used, while not cluttering the interaction space. The *increase / decrease instrument* can also be used to resize documents by touching their borders and to zoom in on images or increase text font size (Figure 4).

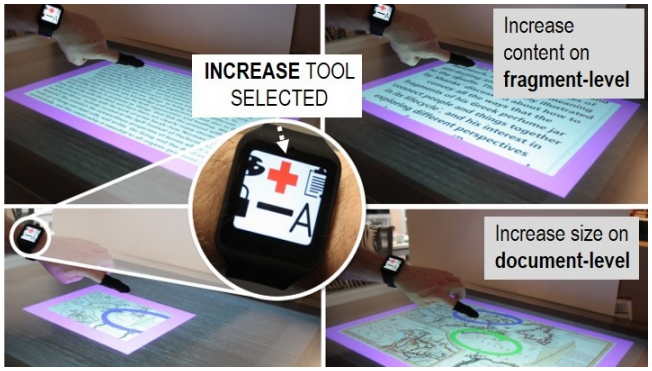

Figure 4. Using the *increase* instrument.

Since Lisa sits opposite John, he uses the manipulate instrument to spatially organize documents on the surface, by moving them around, rotating them using simple gestures, or to resize them. The manipulate instrument can be used on whole documents, as well as image and canvas fragments. John looks through the photos. Using the manipulate instrument, he can crop, resize, and rotate the image fragments. John shows Lisa the text he has been working on. He increases the font size, for easier reading.

Share access to a document with other users

Finding and sharing artefacts (digital and physical) with collaborators is one of the key curation activities, allowing more insight to be gained [33, 40]. However, not all content should be editable by everyone as people care about their personal data and boundaries [8, 37]. In *CurationSpace* documents are therefore owned by an individual person and cannot be manipulated by others unless explicitly shared. Using the share instrument, the ownership of multiple documents can be changed through the touch of an authenticated finger.

Lisa wants to erase a paragraph of text in a document. She selects the erase instrument on her watch and attempts to erase the text. However, John has not granted her access to the document so she can view it, but not edit it. In order to share the document, John selects the share instrument on his watch, and applies it to the document with an authenticated touch. This transfers the ownership of the document to the public, making it editable by anyone. Lisa can apply the same instrument to the public document, transferring ownership to her.

Edit content, documents, and fragments

As part of the curation activities, documents are also analyzed and reworked into new representations. Text needs to be deleted, important area marked on a map, or essential paragraphs in a text highlighted. In *CurationSpace* various editing instruments (e.g. color instrument to draw, highlight or change text color, see Figure 5) are available for these tasks. Using instruments, a user can rapidly multitask between different objects. For example, John can highlight sections of text as well as visually mark sections on a map.

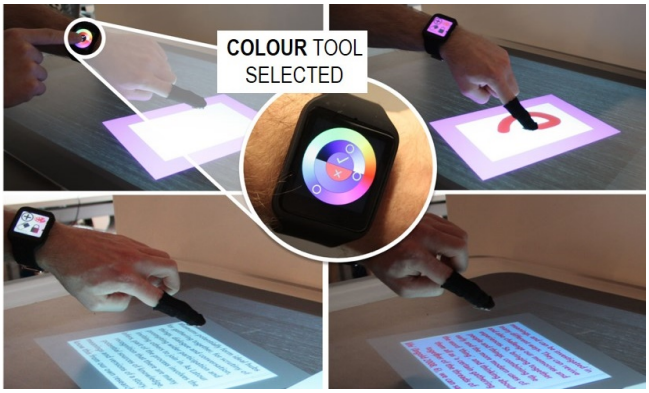

Figure 5. Using the color instrument, the user can set the paint of his drawings or change the color of text.

John has a draft chapter about the hospital at home, on which he wants to work further with Lisa, while also marking key spots on a map. He uses the create instrument to add a text fragment to a document. He then uses the color instrument to change the color of text when highlighting it and to draw on the map. Together Lisa and John mark places on the map with their occurrence in the text in the same color.

Erase to delete content, fragments, and documents

The erase instrument works on fragments or their contents, but also on whole documents. Once selected, a user can for example erase drawings on a canvas (Figure 6 top) or selected text, remove images, or delete entire documents (Figure 6 bottom). This helps to keep the curation space clean by quickly erasing unneeded content.

One of the photos is irrelevant for the current chapter. Lisa selects the erase instrument and applies it to the image. In fact, she can delete any fragment or entire objects by touching their borders. Applying the erase instrument to the inside of a fragment allows her to remove part of the content, for example to erase parts of a drawing on a canvas or an image, or to delete parts of a text by selecting it.

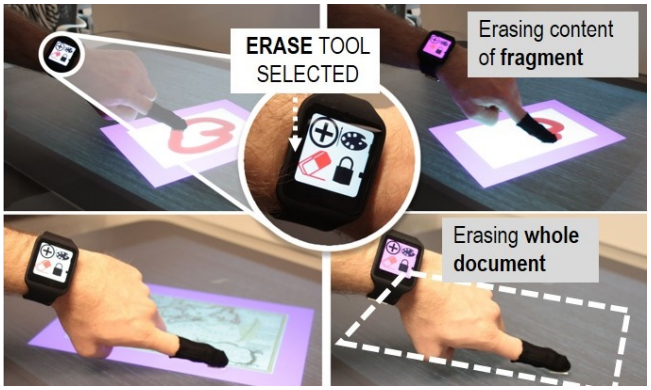

Figure 6. The *erase instrument* can be used to erase drawings on a canvas or image (top) and to erase documents (bottom).

The watch as a clipboard and document repository

Non-public documents are marked in their owner's color. When disconnecting from *CurationSpace* by covering the watch with the entire hand, all documents are saved on the owner's smartwatch, removing all private documents from the shared space. To clear up space, documents can be docked as icons to the sides of the interaction space using the manipulate instrument (Figure 3) or the decrease instrument.

Lisa wants to continue working on a text at home, and gives John a copy of the text. She uses the copy instrument to duplicate the document, and transfers ownership of one of them to John using the share instrument. When disconnecting, the documents are offloaded to their smartwatches. At a later time, instead of creating new documents, they load previously used documents from their watch: when using the create instrument, previously created documents are available.

USER EVALUATION

To evaluate people's interaction with the instruments in *CurationSpace*, we conducted a scenario-based user study. The goal was to learn from participants' appropriation of *CurationSpace* for curation tasks and gather user feedback about the understanding of its basic concepts and techniques.

Procedure

We recruited 8 participants (4 female; 27-35 years old, mean 30) from different backgrounds (historian, librarian, financial consultant, civil servant, researcher). Participants rated themselves as average to experienced computer users (median=3.5; iqr=1 on 5-point Likert scale) and to be experienced using multiple devices (average number of owned devices=4.12; stdev=0.6 including smartphones, smartwatches, tablets, e-reader, laptop and desktop PCs). Participants were introduced to the task, signed a consent form and answered a pre-questionnaire. We then asked them to complete a scenario using *CurationSpace*. Each smartwatch was preloaded with photos, text, and maps. Participants were asked to complete both individual and collaborative tasks; a researcher acted as their collaborator. They were guided through their tasks and asked to think aloud. After completion, a semi-structured interview and post-study questionnaire followed.

Participants enacted the following scenario: they are meeting with a collaborator to work on a report about architecture and landscapes in London. The report should eventually consist of images and text about the topic. Prior to the meeting they created a pre-selection of images and text and preloaded them to their smartwatch. They were asked to add content (images, drawings, text) to the shared space; explore images, maps and text; create new sketches; highlight sections of images or text; delete parts of drawings, text or entire documents; group and arrange content; and share it with their collaborator. These tasks required users to go through the content on the watch, add them to the interaction space and use various instruments (color, erase, increase, decrease, create). The aim was to explore the core tasks of curation supported in *CurationSpace* (collecting, analyzing, editing, sharing).

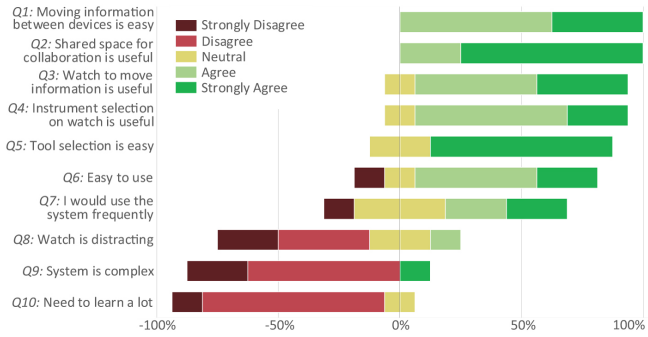

Figure 7. Results of the 5-point-Likert-scale of all 8 participants to the post-study questionnaire about CurationSpace.

Results

User Feedback: Figure 7 shows an overview of participants' answers from the post-study questionnaire. Participants found the system easy to use (Q6. Md=4; iqr=1.5 on 5-point Likert scale). Although one participant found that the watch distracted him from his main task, most participants found the watch useful (Q8. Md=2; iqr=1.75) and it was generally seen as a useful companion for tool selection (Q4. Md=4; iqr=0.75). Participants found it useful to share personal data from the smartwatch to the shared space (Q3. Md=4; iqr=1) and all participants agreed that moving information between watch and shared space was easy (Q1. Md=4; iqr=0).

Understanding of instruments: The scenario was set up in a way that participants' learned the system on-the-fly. They

explored the functionality of the smartwatch and its interaction with the shared surface through the task and did not have a high learning barrier (Q10. Md=2; iqr=0). Users understood that instruments were atomic tools that could be applied to the space, a document or the content of a document. For example, P7 used the increase/decrease instruments to change picture and document sizes. Later, she wanted to replace an image with a different one and decided to try the erase instrument because she thought it could be applied in a similar way as learned before with the other instruments.

Order of applying instruments: *CurationSpace* follows the principles of reification, polymorphism and reuse [5], in that an instrument can be applied to different objects of interest. Users expected instruments to work similar to existing tools in GUI (such as Microsoft Word), where the order of application is different: object selection first, tool selection after, whereas in *CurationSpace* it is the other way around. Although all users understood how instruments worked after experiencing one instrument across multiple domain objects, initially different expectation about their mode of operation sometimes led to confusion. P3 summarized his understanding of how tools work: *"the tools seem to work forward, rather than on previous selections. Rather than selecting something and then selecting the tool, I have to select a tool and then apply it to something. Which is counterintuitive to what I am used to in a desktop PC.*" He continued: "*this system differs very much from my current working style. For example, I see that [the erase tool] works like a regular eraser with a pencil drawing, but I feel like I need to unlearn a lot of things [in order to use it]."* On the contrary, P4 argued: *"once you know which way it works it's easy. [Pick up an] instrument and go"* and P8 notes: *"It's different from how I use [tools] on a computer, but similar to a pencil. So I guess it's just a mind-set."* P6 suggested a new *transparent-instrument*, which could reverse the order of operation: First he selects an object using this instrument and then applies, say, the color instrument afterwards.

Awareness and conflicts: The smartwatch provides personalized feedback to the user, showing which tool was currently selected. When moving their attention away from the watch to collaborate on the shared space, we observed situations where users forgot which tool was selected. For example, after deleting some text, a participant sat back to proofread the result. She then wanted to rotate the document to share it with her collaborator. Since the erase-instrument was still selected, the entire document disappeared: "*I expected it to confirm first. But it's handy, you just have to know that it's gone once you apply it*" - P7. As a solution P2 said "*I'm a forgetful person. So I imagine if you have done a lot of work together and then erase a little bit and forget to switch it off, I might accidentally erase something. […] A small pictogram of the selected instrument on the shared screen or confirmation if you are about to delete something would be good*". P3 suggested a timeout to automatically deselect a tool after an amount of time not using it.

Use in real world practices: Overall, most participants could imagine themselves using *CurationSpace* in their curation workflows (Q7. Md=3.5; iqr=1.75): "*it is much easier to share information between multiple people rather than watching it behind your screen*" (P2). P7 adds that she "*can be selective and only share what [her] colleague needs, who in return can then select [what] he wants to have on his watch and not bombarding him with all the documents*". P5 reported that she does not see any application of the system in her current work: "*I do everything electronically and send it and talk about it via email*". P3 suggested "*if [the shared space] were in a different format, say a large whiteboard, where it was more a presentation format, rather than an intimate format, then I'd see much more of an application for this*". P3's mentioned that he does not see any advantage of using *CurationSpace* in his work: "*I print everything and it's a lot easier to do all of these things with paper*". P7's perspective differs: "*we have all the documents online and it's not like we print anything anymore. I was working with a colleague earlier, and we had to squeeze in font of one computer, but couldn't work together at the same time*".

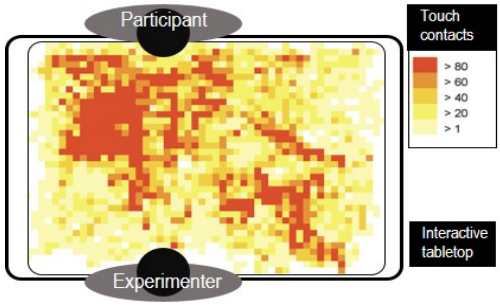

Figure 8: Heatmap of participants' touch patterns on the shared space, showing the main interaction zones.

Usage of space: Participants appreciated a shared space for group work (Q2. Md=5; iqr=0.75). The instruments of *CurationSpace* did not hinder the interaction with the tabletop, as the observed usage pattern reflect similar observations in prior work [37], where group, personal and storage territories exists. Figure 8 shows the usage patterns across the shared surface of *CurationSpace* (except P3, as this data file was corrupted) . Participants were seated to the top left, their collaborator was seated across from them (bottom left). Participants usually started their interaction in the space in front of them and then shared documents by moving them to free space on their collaborator's side (bottom right).

Privacy: Most participants saw the benefits for co-located group work and using a personal device for selecting shareable data. "*There is an element of privacy when selecting documents from a smartwatch. If you are using it in a really collaborative setting I am happy for everyone to see everything. But with different stakeholders or sensitive data, then it is much better to use it on a personal device*" (P1). P2 compared it using the smartwatch to opening images from a folder: "*It depends a bit on what information you are sharing with who. If it's a good friend, I wouldn't mind that they see pictures I didn't want them to see. If it's my boss, I would not*

want them to see everything. [CurationSpace] is much better in only showing what I want to show." And P1 added "*I have most of the information already located on a cloud based service [which is connected to my] smartwatch. So I wouldn't need to bring a USB stick or anything else*."

Suggestions for tools: Participants suggested further instruments: P8 wanted to rearrange 12 different documents on the shared space and felt it was cumbersome to do so with the manipulate instrument because it meant rotating, moving and resizing every single one. She suggested to add predefined sizes, positions, rotations and orientations within the manipulate instrument that could be applied with a single touch to any document. P2 suggested a share instrument to "*save everything on the table itself, but also you could select if you want to save it only on your watch or on the other's watch*". This could also be extended to save the entire state of the system, allowing users to resume a curation session later.

DISCUSSION AND CONCLUSIONS

CurationSpace was designed to provide a new document presentation system that applies the concepts of Instrumental Interaction [4] and dynamic media [18] to content curation of historical documents on interactive surface. A distinguishing feature from other cross-device systems is a clear separation between the interaction space, the high level documents of interest, the atomic fragments that make up the documents, and the instruments that are used to modify or create content. The interaction techniques and document model presented provide an example of how smartwatches can be utilized to augment human touch with a vocabulary of interactive instruments that allow for menu-less content curation resembling interactions with physical documents.

Hardware limitations: To authenticate a user on the tabletop display, our system uses fiducial marker attached to the fingertips of a glove (similar to TouchID [25]). However, with the advent of novel touch sensing technologies, in the future screens will be able to identify a finger through internal sensors, e.g. as proposed in DiamondTouch [11], with IMU sensors such as in SwipeID [19], through fingerprint sensors in a touch screen [15], or use top-mounted tracking systems (e.g. GroupTogether [24] or HuddleLamp [30]) combined with gesture recognition on the smartwatch.

Use of smartwatches for instrumental interaction: Although previous systems have proposed related interaction techniques to allow for cross-device information management, privacy applications, and personalized content, these are mostly based on smartphones interacting with the table. Compared to watches, smartphones are harder to manipulate, take up space on the table, and are not particularly suitable for many of the instruments introduced in *CurationSpace.* Furthermore, the ability for users to pass around or share tablets and phones as (semi) shared devices creates operational inconsistencies connected to identifying the user, or maintaining the user's personal information repository. In contrast, smartwatches are rarely passed around and thus are a much more suitable personal "passport" of the user.

Through the user study we found that *CurationSpace* in its current form is easy to use and participants found it well suited for collaborative tasks. The tasks in the user study followed our initially introduced scenario. We found the main curation tasks were effectively supported; participants were able to review, edit and share documents with their collaborator. Although the order of applying instruments to domain objects follows the interaction mode with physical tools (pick up first, then use) rather than GUIs (selection first, then pick tool), this model was understood by participants but needed learning. In particular, with sensitive content or in more formal social settings, participants saw benefits of a private, body-worn content repository. Although the smartwatch application showed the currently selected instrument at any time, some participants, while discussing their curations works, forgot which tool was selected. This should be considered in any future work, for example, the system could either provide mediation (e.g. timeout or confirmation with the erase instrument) or a more prominent status feedback, in particular with critical instruments. The user study lasted approximately one hour and throughout this this time we saw how participants got accustomed in sharing and editing documents. However, real world curation activities usually last longer and might span across multiple sessions different days.

Generalizability: The concepts, document model, and watch-centric instrumental interactions can be applied to other domains, applications, and user groups beyond content curation. *CurationSpace* introduces users to a reconfigurable shared and instrumented configuration space [16] that allows users to modify any content that can be modeled, visualized, and shared in the `<space, document, fragment, instrument>` structure. Furthermore, the intrinsic separation between instruments and documents allows for great flexibility to extend the system with many new instruments, or even customized combinations of instruments.

We are currently expanding *CurationSpace*'s concepts to further curation tasks, including expanding the document model to the physical space, allowing users to use both physical and digital documents. By creating consistency between how people interact with digital and physical documents, the aim is to provide users with a uniform interaction model across digital devices and physical tools for curation work.

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