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Supporting methodic design practices with interactive organization and visualization of design artifacts

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by

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To my parents.

Erklärung

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Arbeit selbstständig und ohne fremde Hilfe verfasst, andere als die angegebenen Quellen und Hilfsmittel nicht benutzt und die aus anderen Quellen entnommenen Stellen als solche gekennzeichnet habe.

Konstanz, November 21^{st}, 2011

Anita Höchtl

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Vorwort

Die folgende Arbeit zeigt, dass die Umgebung von Designern durch den Einsatz berührungsempfindlicher Oberflächen, der entsprechenden Visualisierung und einem adequaten Interaktionskonzept besser strukturiert werden kann. Dies fördert vor allem die Überschaubarkeit der vorhandenen visuellen Artefakte im Design-Raum. Die ursprüngliche Idee die Blasen-Metaphor für die Anordnung von visuellen Artefakten auf berührungsempfindlichen Oberflächen zu verwenden enstand während meiner Tätigkeit als hilfswissenschaftliche Mitarbeiterin in der *Arbeitsgruppe Mensch-Computer-Interaktion* im Projekt *Blended Interaction Design*. Dabei stand vor allem die Verbesserung der aktuellen Gruppierungs-Technik des *AffinityTable*s [18–20], einem hybriden System zur Unterstützung der Kreativitätstechnik *Affinity Diagramming*, im Vordergrund. Sehr schnell stellte sich allerdings heraus, dass im Speziellen die Oberfläche *Blub* Potential für die flexible Arrangierung visueller Artefakte im gemeinsam genutzten Design-Raum hat.

Mein besonderer Dank gilt daher *Florian Geyer, M.Sc.*, der mich durch seine hohe fachliche Kompetenz und die stete Förderung während der Durchführung und Fertigstellung dieser Arbeit unterstützt hat. Für die anregenden wissenschaftlichen Diskussionen, das umfangreiche Feedback und die Bereitstellung der Hardware und Software bedanke ich mich bei der gesamten *Arbeitsgruppe Mensch-Computer-Interaktion* unter der Leitung von *Prof. Dr. Harald Reiterer*. Überdies gilt mein Dank *Peter Hering, M.Eng.* für die Korrektur der Typografie. Vor allem aber möchte ich mich bei meinen Eltern für die großartige Unterstützung während der gesamten Zeit meines Studiums bedanken und ihnen diese Arbeit widmen.

Kurzfassung

Die vorliegende Arbeit beschäftigt sich mit der Unterstützung von Designern in deren Umgebungen. Die Anordnung und die Visualisierung von Design-Artefakten, wie Fotos, Zeichnungen oder Skizzen, auf digitalen Oberflächen stehen dabei im Vordergrund.

Neben einer Einführung in den Design Prozess, steht die räumliche Umgebung von Designern im Fokus. Dabei wird der Anspruch einer Art formalen Organisation für den kollaborativ genutzten Raum verdeutlicht und der Umgang mit den visuellen Ressourcen der Designer analysiert. Diese gemeinsam genutzten Oberflächen können durch digitale Technologien wie zum Beispiel berührungsempfindlichen Bildschirmen unterstützt werden. Um einen adäquaten Gebrauch dieser zu ermöglichen sind sowohl die Visualisierung als auch das Interaktionskonzept von hoher Relevanz. Zu diesem Zweck, werden verschiedene Anordnungsmöglichkeiten betrachtet und bereits bestehende Systeme hinsichtlich der Gebrauchstauglichkeit im Design Kontext überprüft. Aus diesen Analysen und auf Basis verschiedener Design-Prinzipien werden zwei Oberflächen, deren Aufgabe die Strukturierung von visuellen Artefakten ist, vorgestellt. Die Durchführung einer vergleichenden Benutzerstudie auf einem Tisch mit berührungsempfindlicher Oberfläche gibt einen ersten Einblick in die Bedienbarkeit derer. Die anschließende Diskussion beschäftigt sich mit der Adäquanz dieser Oberflächen für die Gruppierung visueller Artefakte, der Leistungsfähigkeit der Benutzer während der Verwendung derer und den subjektiven Präferenzen der Benutzer. Desweiteren geben die Ergebnisse Aufschluss über die angewandten Interaktionsstrategien und zeigen die Verwendung von beidhändiger Interaktion sowie der Benutzung mehrerer Finger zur Bedienung der Oberfläche. Abschließend werden Rückschlüsse auf den Design Kontext geschlossen und Vorschläge zur Verbesserung beider Oberflächen gebracht.

Im Hinblick auf zukünftige Arbeiten wird ein ganzheitliches System vorgestellt, welches neben der Organisation von Design-Artefakten auf einer berührungsempfindlichen Oberfläche, insbesondere die Ansteuerung von Visualisierungen auf örtlich entfernten Bildschirmen ermöglicht.

Abstract

This work describes the support of designers in their design environment. The focus is on the organization and visualization of design artifacts like images, drawings or sketches on digital surfaces.

Besides a short introduction in the design process, the physical design environment is one main issue. Therefore, the need for some kind of formal organization in a collaborative design environment is highlighted and the dealing with visual design resources is analyzed. These shared surfaces can be supported by the use of digital technologies such as touch-sensitive surfaces. The visualization as well as the interaction concept are of high relevance in order to allow an appropriate use of these surfaces. For this purpose, different spatial layouts are considered and current existing systems are verified concerning their usability in the design space. Two interfaces for structuring visual artifacts are introduced on the base of these analyses and various design principles. The results of a comparative user study, which was conducted on a digital tabletop, give a first insight into the usability of both interfaces. The following discussion is concentrated on the adequatness and effectiveness of these, the user performances and the user preferences. Moreover, results explain the applied interaction strategies and show the use of bi-manual and multi-finger interaction. Finally, conclusions concerning the design space are drawn and suggestions for future improvements are made.

With regard to future work, a holistic system, which provides a remote control for visualizations on large displays besides supporting the organization of design artifacts on a digital surface, is presented.

Chapter 1

Introduction

The design process from the first idea to the design solution is like a flower. This flower needs water to grow and fertilizer to resist against external influences. Then the flower can begin to bloom. After some time the flower is getting older and older and needs care in order to bloom again.

The growth of the flower can be compared with a whole design process. Figure 1.1 illustrates the single parts therefore. The leaves of the flower constitute the different design phases. Single design artifacts flow in the veins of the plant. The stem becomes smaller with the increasing height of the plant, which means that not all design artifacts reach the top. The bloom is formed by a selection of the most important artifacts. The beauty is an expression of the quality of the design material. Once burst into bloom, a growing plant needs care. This means, that after a while a design solution becomes boring and new design ideas have to be prepared to enthuse the target audience again and again. For this purpose, brown leaves are removed and water as well as new fertilizer is given to the plant. So, design artifacts are carefully rejected and space is available for new ideas. However, if a prior design idea was good, the reuse of it in whole or the use of particular artifacts is a good base for firing off new blooming ideas. Design artifacts, which have not been used can be promising for other projects and can show new perspectives as a specific single flower can be dreadful, but seeing the plant in an environment of flowers, can unfold its full beauty.

1.1 Reflection

Equally important is the environment, where the flower is growing. Therefore the ground as well as the lighting conditions and the temperature influence the plant's growth. This means that the involvement of several designers in the design process multiplies the input for creating an idea. This makes reflective conversations possible, which are usually unavailable for single designers [57]. Reflection is an essential aspect in the design process and can be described as decision-making instrument. Reflecting allows to view an idea in more detail. *Reflection-in-Action* [51] describes the conversation of designers with a situation. Designers critically reflect a main problem, reframe it, try to work out the consequences and run through different ways to solve the problem. The whole process of *Reflection-in-Action* is

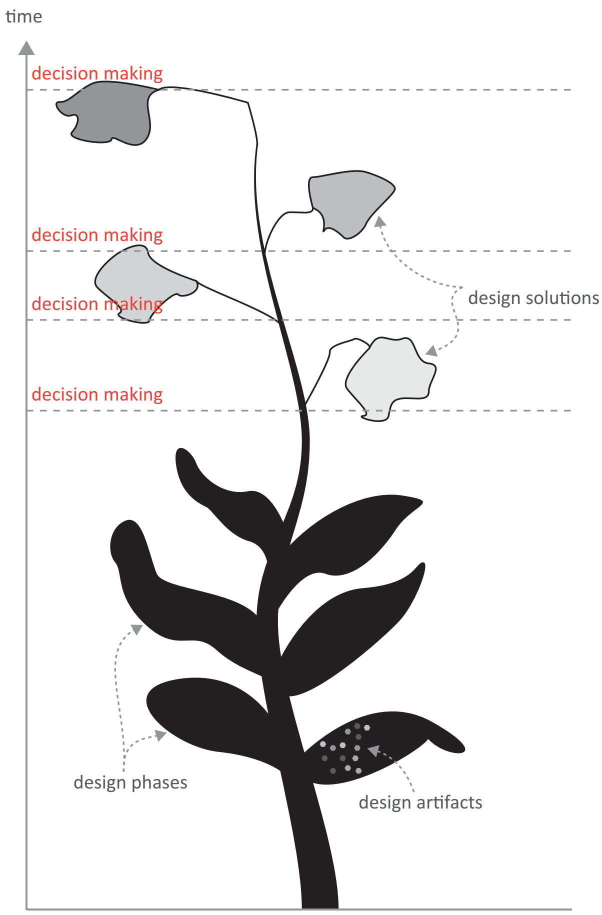


Figure 1.1: Design process flower.

the continuous interplay between the designer and the situation. Prototyping as Iterative Incremental Refinement [12] can be compared with *Reflection-in-Action*. In Figure 1.2, the enhancement of the situation is shown by the red arrow. The spiral reflects the process of Reflection-in-Action. Reflecting in a group typically consists of three phases: *Reflection*, *Planning* and *Action* [16]. In the designer's context, *Reflection* is the critical thinking about several design ideas. *Planning* considers each alternative and guides each designer to the intended action. *Action* leads the designer to the goal-directed behavior itself.

1.2 Convergent and divergent thinking

Reflection is closely related to convergent and divergent thinking. As shown in Figure 1.3, numerous distinct branches are created in the early phases of the design process. Various design alternatives are more or less refined and can break up into new branches [12]. At a certain point, designers make a choice of the most promising ideas, options and alternatives for a final design solution. This phase is followed by convergent thinking, which helps in focusing on one or more alternatives for the ongoing design process.

Figure 1.2: Prototyping as Iterative Incremental Refinement [12].

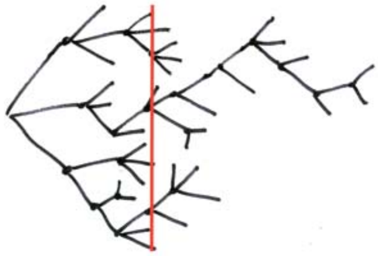


Figure 1.3: Design as Branching Exploration and Comparison [12].

1.3 Design is a choice

Design is about exploring and comparing the created alternatives. According to Buxton [12], there is not just one right path, but rather there are several paths which should be taken into account at any given time, regardless of whether a special idea is realized in the final product or not. The point is, that making decisions is indispensable for the progress of a design solution.

1.4 Outlook

This work focuses on supporting designers in their methodic design practices. Chapter 2 analyzes the different surfaces, which are typically used in a designer's environment, gives an introduction to Design Knowledge Management (DKM) and shows how this can be supported by the use of digital surfaces. Chapter 3 delineates reasons for organizing information and shows the most common used spatial structures in human-organized layouts. Afterwards, design goals are specified and currently existing spatial layouts are analyzed. Chapter 4 presents the Design Rationales of the two interfaces, Blub and Bin. Chapter 5 describes the conducted user study. The primary focus was to find out, if the concept of Blub works on digital tabletops and can be understood by users. Chapter 6 discusses the results of the user study concerning adequateness and effectiveness, user performance, user preferences, interaction strategies and gestures and examines design implications for both interfaces. Chapter 7 concludes this work and draws a bow to the earlier defined requirements and Chapter 8 presents a holistic system for supporting a designer in his methodic practices and introduces *ReSi* - an interactive remote control by using Sifteos [42].

Chapter 2

Design space

Designers work in an environment full of informative and creative design artifacts. Walls and surfaces enrich the atmosphere and help the designer to gain inspiration. In the following, the different types of surfaces in a creative environment, their classification, their purpose and the activities in the design space are shown. The term *Design Knowledge Management (DKM)* is defined and requirements for the support of DKM in the digital space are specified.

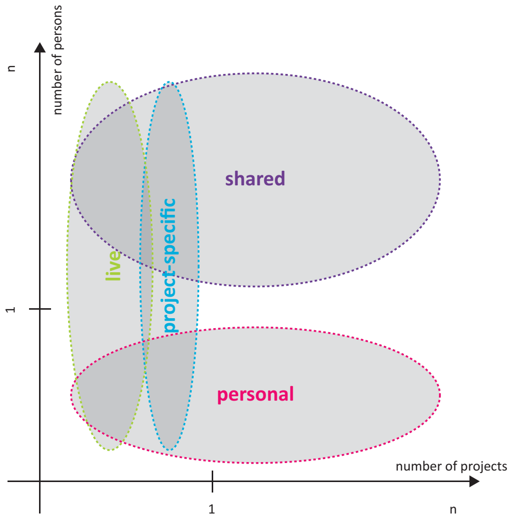
2.1 Surfaces

In the work environment, several surfaces enrich the design space. The variety of desks and whiteboards, which are used in the designer's environment, can be classified into four categories by considering the purpose, the number of projects for which they are used and the number of individuals making use of them [58]. These four surfaces are:

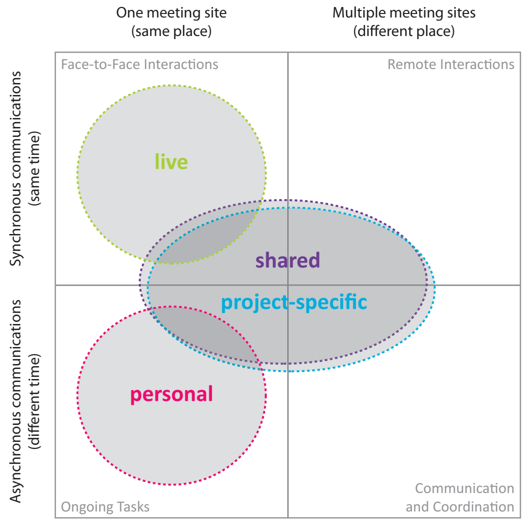
- Personal,
- shared,
- project-specific and
- live-surfaces.

Personal surfaces are only used by one designer. Artifacts on this surface include design sketches as well as ongoing project-related information, physical models, prototypes and personal information. The functionalities range from consulting with colleagues about shared artifacts, organizing individual time and project management to supporting the individual's creative thinking.

Shared surfaces assist a group of designers in sharing design knowledge related to specific projects. Usually the shared surfaces are created and used over a long time period and need a kind of formal organization as they are used by several users.



(a)



(b)

Figure 2.1: (a) *Artful Surfaces* [58] arranged to the dimensions number of persons and number of projects. (b) *Artful Surfaces* [58] categorized concerning time and place in Baecker's version of the CSCW-Matrix [4].

Project-specific surfaces are more related to a specific project than the other surfaces mentioned. These surfaces gain a high degree of flexibility (e.g. movable whiteboards) and are frequently used for organization, management and reflection on a specific project. This type of surface is adapted for either synchronous or asynchronous tasks and acts as a mediator of social coordination.

Live surfaces support real-time collaborative activities (e.g. explicit design techniques).

2.2 Persons and projects

Figure 2.1a illustrates the four types of surfaces arranged regarding the number of persons who use the surface and the number of projects which can be shown on the specific type of surface.

Live and project-specific surfaces are typically just for one project. A live surface is the most short-lived type as it is used during the appliance of a specific creativity technique for example a brainstorming session. In contrast to that, a project-specific surface is existing on the duration of its project. This can range from one week to a few years depending on the purpose, the size and the financial resources for the project. A personal surface is the daily working place of a designer. The most common used space in a design environment are shared surfaces. Multiple designers benefit from the inspirational nature of this surface and use it across projects.

Shared surfaces have the greatest potential to influence the work of designers positively as these are always present and enrich their environment with visual resources.

2.3 Time and place

Using Baecker's CSCW-Matrix[1] [4], which consists of four quadrants, the distinct surfaces can be arranged in relation to the dimensions of synchronous / asynchronous time and same / different place.

As Figure 2.1b shows, live surfaces act in face-to-face interactions, which means that these surfaces assist a group of individuals in working together at the same time, in contrast to personal surfaces, which support the individual in ongoing tasks. Personal surfaces are designers workplaces and so this place will mainly stay the same. Both, shared and project-specific surfaces are for individual and collective purposes. Consequently the interaction can be synchronous and asynchronous. Concerning the place, project-specific surfaces are mostly more flexible than shared surfaces, but shared ones are being used over longer time periods as they are in the majority of cases for more than one project. The major difference between shared and project-specific surface is the purpose, as the latter one has an organizational character and the first one supports the organization of design artifacts.

As introduced in Section 1.1, the design process consists of different phases which can be broken down into two main activities: creating design artifacts (*Action*) and discussing ideas and solutions (*Reflection*). Design techniques such as Affinity Diagramming, Brainsketching or Storyboarding are mainly related to the first of the major activities and will mostly be executed on live surfaces. During the design phases of creation, designers begin to reflect on their work [51]. In this phase the whole project with all the produced design artifacts is considered. The creation phase is asynchronous and takes place on live surfaces. Discussions either take place on live, project-specific or shared surfaces. Especially shared surfaces are interesting for the reflection of ideas as artifacts on this artful surface are mostly cross-project or project-independent and just for inspiration.

In the following, the focus is especially on these shared surfaces, as the work is concentrated on the support of the reflection of design artifacts in between the different design phases, which is mostly independent from the explicit creation of design artifacts.

2.4 Activities

In consideration of the variety of *Artful Surfaces* [58], the creative environment of designers provides a place for *individual*, *social* and *organizational* activities [47]. Individual means that a surface can serve as a reminder (e.g. TODO lists, current design sketches) or makes information persistent available (e.g. quick references, project outlines). The function of a surface in the social sense is to maintain social identity (e.g. status, role, responsibilities) and professional identity (e.g. certificates) in order to represent a person. The organizational purpose is to give an orientation for communication (e.g. awareness, conversational resources) and for work processes (e.g. resource management). That implies that displays can initiate fruitful conversations, which in turn means that displaying visual artifacts could force the creativity in the design space.

[1] The CSCW Taxonomy was first presented by De Sanctis and Gallupe (1987) as a broad typology of group support systems. Johansen (1988) refined this work and introduced the 2-to-2 CSCW-Matrix with the differentiation between time and place. Baecker et al. [4] republished it in 1999.

2.5 Design Knowledge Management

During design processes a large volume and diversity of design artifacts is created by designers. The design knowledge produced, consisting of a variety of design artifacts, is primarily used for a specific project, although, storing the created knowledge allows the designer to reuse the artifacts at a later time either to gain inspiration or just to generate new ideas for the same or for other projects. In addition, documenting dissenting views and then returning to these views during later consideration can also preserve a cognitive conflict and reflect on the minority dissent [16]. The storage and retrieval of design knowledge is called *Design Knowledge Management (DKM).*

In contrast to *Personal Information Management (PIM)*, the primary purpose of DKM is to support the designer's need to share artifacts with others. Overall, designers are visual thinkers and struggle with finding textual representations for their mental images [54]. One reason more why traditional PIM is not appropriate for organizing a designer's collection of visual artifacts. These collections of design artifacts are mainly very chaotic. Physical and digital, or tangible and intangible artifacts are mixed. Relevant tangible examples are often flagged in books or magazines, but designers forget why they flagged them or forget to review them again. The main question for the designer is "‘Why did I flag it"’ or "‘What about it, did I find particularly worth flagging?"’ [27]. As a result of using electronic strategies, the navigation through a mess of links and cryptic file names is complicated and locating items which are of interest is nearly impossible. If the collected material is used more as an inspirational source, the formulation of a specific search query is difficult.

One major challenge nowadays is not only to find a specific artifact again, but it is more to find the artifact in the medium in which it is stored. The higher the variety of types of resources, the more complex the level of DKM.

2.5.1 Phases in Design Knowledge Management

The early process of managing design knowledge can be divided into four phases [54]: *Idea Generation*, *Collection of Artifacts*, *Storage and Organization* and *Retrieval.*

Idea Generation is the creation of a wide variety of design ideas, which helps the designer in order to understand a problem and find a solution. As already shown in Section 1.2, producing a rich landscape of ideas is especially important in the early phases of design.

Collection of Artifacts stores all produced artifacts so as to provide an inspirational ground for several projects. According to Keller [35], the key aspects of a collection are:

1. A collection is a *whole* which consists of *multiple elements* which share some characteristics.
2. Collections are dynamic objects created by *somebody, over time,* for an explicit or implicit *purpose.*
3. The growth of collections may not always be under *conscious control* of the user - like a garden.

While reasons for keeping things are different, one is common to many designers: Collections do not follow any structure and are a mess. Nevertheless, designers have the need to interact with their collection in order to use earlier produced artifacts. The organization of artifacts is a fundamental activity, which can support the methodic design practices as it allows the designers to visualize the divergent artifacts and to relocate them again. Furthermore, this process includes activities such as structuring, branching and sorting.

Storage and organization is the phase in which designers should begin to structure their artifacts regarding different aspects. The reasons for storing design artifacts are various. According to a number of designers [54], artifacts are stored in order to aid in idea generation, to capture the design process and to share or help others.

Retrieval is directly connected with the previous phase. The reasons therefore are similar to storing and organizing artifacts. Aiding idea generation, gaining inspiration and sharing design information with others initiate mostly the retrieval of design artifacts [54]. In contrast to storing artifacts, comparison and reinterpretation or reflection are further reasons for retrieving design artifacts.

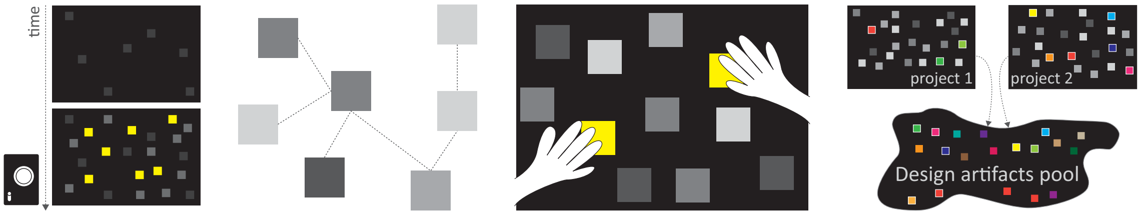
However, to provide a good base for these activities, the organization of design artifacts in an earlier phase is essential in order to support especially the sharing of artifacts with others and the comparison and reinterpretation of design ideas. A designer's environment can be enriched by organizing these visual design artifacts all around in the design space and can act as an inspirational source for the designers.

2.6 Supporting Design Knowledge Management on Digital Surfaces

The previous sections shed light on the importance of various activities that support designers in their work. Now, the emphasis is on the activities which should be supported in the design space. In Section 2.1, the different types of surfaces and their purposes were introduced. The phases of the DKM were shown in Section 2.5.1. As a result of these analyses, four requirements for supporting the designer's activities in DKM can be defined (see Figure 2.2):

- Support in capturing the design process,
- Support in linking related design knowledge,
- Support in sharing design knowledge,
- Support in reusing prior design artifacts.

The following sections introduce the reasons to gain an understanding of why the support of these aspects in particular is relevant for DKM.



(a) (b) (c) (d)

Figure 2.2: (a) Capturing the design process. (b) Linking artifacts. (c) Sharing artifacts with others. (d) Reusing earlier produced artifacts stored in a design artifacts pool.

2.6.1 Support in capturing the design process

During the different phases of a design process, lots of design artifacts are created. These artifacts give information about the result of the distinct phases and moreover the current status of a project. The availability of artifacts to others makes the process more transparent and promotes an awareness among others, whether they are directly involved in the process or not [47, 60]. Furthermore, the clarity of group objectives and reflexivity enhances creativity, while a low awareness of what other group members are doing can lead to a slowdown in design process [57]. Besides, the capturing of data also demands knowledge about the process afterwards. In Section 2.5, the term DKM was introduced and the need for searchable design artifacts was pointed out. Designers often use cryptic filenames for design artifacts in their electronic collections, as the produced design artifacts are not always immediately relevant for a specific project [54]. A system should assist in the complex and extensive activity of creating a well-structured collection in order to facilitate the designer's work by supporting the later finding process. Therefore, the system has to know the designer's demands. For example, the right meta-data can foster searching for design artifacts. Table 2.1 shows the most important artifact attributes, which are considered in the finding process [54].

Table 2.1: Attributes for searching past artifacts [2].

Activity	Responses
Project Name	23
Approximate Date of Creation	15
Artifact Type	15
Location of the Artifact	15
Artifact Name	11
Artifact Content	9
Designers Involved	9
Other (e.g., Client/project code)	3

[2] Sharmin et al. [54] interviewed 28 professional designers for their preferences.

For designers, the most important information to a design artifact is the project to which it belongs. Interesting is also the date of creation, the artifact type and the location of the artifact. Less important are the artifact's name, its content or the designers involved in the creation. This shows, that current electronic systems do not give appropriate support. Current desktop systems require titling of artifacts, but designers were not interested in the name of artifacts. More relevant for them is the context in which the artifact was produced, especially the project in which it is embedded. Therefore, a system could support the designer by providing a functionality to capture the design process at a current state, which means a design artifact is considered in a whole design context. Using a chain of captured pictures allows to tell a story about the development and the progress of a specific idea or solution.

The big challenge in supporting the capturing of a design process is to provide tools for creating a clear overview of the produced material. *But how to present design knowledge in a way that stories, which have been created, can be understood and found again?* And are all artifacts, produced during a given period of time, needed by the designer? And what about the possibility to focus on some details? How granular should the capturing process work?

2.6.2 Support in linking related design knowledge

Linking and building up a network of design artifacts assists in constructing a mental image of artifacts, which are created during the design process. To understand one single artifact without the corresponding context can be hard and is sometimes impossible. Besides, connections between these artifacts give the designer the path in which the artifacts should be read. Moreover, the story associated with the artifacts is conveyed by having the relations in between [54] (e.g. reading the single images of a storyboard out of context). In addition, consulting artifacts with their creator at early, middle and late phases in the design process can also facilitate the later finding process.

Two artifacts can either have a strong relation to another or not. To understand a whole network of artifacts, links in between those open up the meaning and the importance of each artifact [60]. But this raises the question: *How can artifacts from one design phase be connected to artifacts from another design phase?*

2.6.3 Support in sharing design knowledge

Presenting design knowledge is also a conversational resource responsible for initiating and scaffolding conversations [47]. A group of designers has more ideas than a single designer alone. That is one reason why the sharing of one's own ideas and discussion within a team is a promising way for getting a better design idea or solution. According to Arias et al. [3], complex design problems require more knowledge than any single person possesses. Bringing different and often controversial points of view together creates a shared understanding and can lead to new insights, new ideas and new artifacts.

The *Resource Sharing Concept* depicts that collaboration between individual designers is an essential aspect in designing and reflecting ideas [59]. Sharing artifacts is an important daily or at least weekly activity for the majority of designers [54] as it allows them to learn from one other, to compare ideas, to reinterpret and reflect design solutions, or to just tell a story.

Visualizing a landscape full of flourishing ideas could enhance the designer's skill of creating new fruitful ideas. A tool could assist in sliding through this landscape of design artifacts in a smart and proper way. Getting an overview is also an issue particularly in collaborative settings. Important is that designers have the possibility to interact with those design artifacts in order to create a shared understanding by presenting and reflecting ideas. Furthermore, an appropriate organization of this design knowledge could enrich the design space in inspirational nature. Nevertheless, the main question is: *How to provide a tool that gives an overview of the created design knowledge and that assists in flexible spatial arrangement at once?*

2.6.4 Support in reusing prior design artifacts

Prior design knowledge, whether produced by the designer himself, his colleagues or any anonymous designer, is extremely valued in early design activity. Designers' gaining inspiration and reflecting of past processes is assisted on the base of this knowledge. Designers, furthermore, have an increased awareness of new trends [54]. Artifacts out of magazines can also aid in gaining inspiration. The big problem is to find all this knowledge when it is needed.

The search for specific artifacts can be active - the designer knows exactly what he is looking for, or passive - he just wants to get some inspiration. Designers are not generally seeking specific solutions - they are seeking direction [54]. However, either for finding a specific artifact again or just to gain inspiration, artifacts should be found again. Therefore, a system could provide support with an appropriate visualization and the right interaction techniques. Some designers compare designing with cooking and the design artifacts with the ingredients [27]:

> "'You may not like a recipe, but you like some of the ingredients in the recipe. So you take what you like, maybe add in some new ingredients and create a new recipe."'

In order to prepare a good meal, a cook has to know where he can find the ingredients in the kitchen. A whole mess could spoil the cook's party and the guests' appetite as the main task is then to find things again and not to cook. The same can be applied to the designers' environment. If the whole design space is chaotic and nobody knows, where already produced design knowledge can be found, the sombre mood suggests as much and the true task is put in the background. Therefore, the organization of visual artifacts should be carefully supported so that designers can focus on the creation of new ideas.

Beyond a tidy environment, the appropriate combination of high-quality ingredients sets the stage for a promising design solution. Thus, the designer needs susceptibility to find the right proportion of design artifacts to let the user know the true promise of the design solution.

The three factors, which should be considered, are:

- the ingredients themselves,
- the combination and
- the proportion between them.

This means, that not only a single design artifact can express a whole design solution. The context, which is the combination of artifacts or their spatial relation, should be considered so as to understand an artifact. The right proportion of old and new artifacts helps in creating a clear picture of a design solution and adds the final touch to it. The use of a digital system could improve the task of creating such a clear picture by providing spatial layouts, which are flexible and afford a kind of structure in order to express relationships and have still an overview at once.

The need for reusing artifacts in designing is indisputable, as not every project can start right from the scratch. The main question is: *How to support designers in finding the right artifacts at the right time?* Is it possible to create a tool which allows the designer to be chaotic on the one hand and to find artifacts in a shallow, unstructured system again on the other hand?

2.7 Summary

This chapter introduced four different types of *Artful Surfaces* [58]: *personal*, *shared*, *project-specific* and *live*. Analyzing these surfaces concerning the number of persons who use it and the number of projects which can be shown on the surface has delineated, that shared surfaces have the greatest potential to improve the designer's work. Shared surfaces can not be uniquely specified in regards of time and place as they are mostly used by multiple persons and for more than one project. The activities of the different types of surfaces are either individual, social or organizational. The latter one means that surfaces can initiate fruitful conversations, which could enhance the reflection of previous created artifacts and may force the creativity of the designers.

Design Knowledge Management (DKM) is the process of storing and retrieving design knowledge. The big difference to usual Personal Information Management (PIM) is the purpose as design collections are primarily used to share artifacts with others. As those artifacts are mostly visual, designers would struggle with textual representations, which are used in desktop environments, and would like to have a chaotic organization of their artifacts in order to create own mental images of the design knowledge. The phases in DKM can be divided into: *Idea Generation*, *Collection of Artifacts*, *Storage and Organization* and *Retrieval*. For all these phases, the organization of design artifacts is essential in order to gain inspiration, or share, compare and reflect ideas in a group.

To support the organization of the design space by using digital surfaces, a system should provide support in *capturing the design process*, *linking related design knowledge*, *sharing design knowledge* and *reusing prior design artifacts*. So as to capture the design process, it is important to know, how much detail a system should provide. A clear overview is essential as otherwise, the user will get lost in the flood of design knowledge. To express relationships between artifacts, linking is one possibility. An alternative is to use spatial layouts as the arrangement of artifacts can give a clear understanding of a design solution and the arrangement can tell a story. For creating such a layout, a flexible layout is needed. Sharing artifacts with other designers can enhance the design process. A system could assist in sliding through the variety of design knowledge and in getting an overview. Designers are visual thinkers. Anyhow, for the reuse of artifacts, a kind of formal organization [58] is indispensable as otherwise earlier created design artifacts wont be found again and designers have to start right from the scratch.

The next chapter follows up the question of how spatial layouts can support the design process. The goal is to find a spatial layout which allows to create a mental image on the one side and gives some structure for a better overview on the other side.

Chapter 3

Spatial Layouts

Several studies found out that people need a certain measure of formal organization whether in the physical or digital space [31, 40, 41, 55]. The degree of organization is dependent on the artifact types and the number of objects and the purpose, as there is a difference between organizing visual artifacts of a designer or organizing documents of a lawyer. As concluded in the last chapter, designers can be supported in organizing their design space especially by providing a flexible structure for arranging design artifacts on their shared surfaces. In this chapter, the reasons for organizing information and knowledge on a more general basis are introduced, design goals for an appropriate flexible spatial layout, which can be used in the design space, are defined and existing spatial layouts are analyzed on the basis of these goals.

3.1 Reasons for organizing information and knowledge

According to Malone [40], desk organization has two major goals: reminding the user of things to do and the categorization of information. The following sections introduce these goals and point out the main problems of arranging artifacts in the digital space.

3.1.1 Reminder

Spatial arrangement has four concerns: visibility, spatial memory, scanning and focus respectively periphery [34]. The visibility of artifacts works thereby as reminder for things to do. For example, piles on a physical desktop remind people of tasks to be completed. Reminding can happen *by instance*, *context* or *structure* [6]. Reminding *by instance* means that the object indicates the purpose of this artifact. If one artifact makes only sense in a group of other artifacts, the artifact reminds *by context*. For example, a picture of a screw head may only be recognized in the context of pictures with whole screws. Reminding *by structure* means that the arrangement of artifacts alone is informative for the person. For example, the number of pictures grouped on a whiteboard indicate that this is the most important project for the team. There are several possibilities to remind the user of high priority tasks on a computer system. Frequently accessed files could be displayed on the top of piles on the desktop or could have bigger icons. Other possibilities are to place these files in a prominent location or to highlight them by different colors [40]. Reminding is still one major goal of spatial layouts and should be supported by a system, which purpose is to help designers in organizing visual artifacts.

3.1.2 Categorization

Categorizing artifacts is especially important for the finding process. The process therefore can be divided into three phases: *creating classification*, *classifying* and *retrieving information* [40]. Creating classification is uncommon in physical but usual in digital environments. Titling information can help in the digital space to find artifacts again more easily. Concerning classification of information itself, three different possibilities exist [40]. *Multiple classification* means that artifacts can be put into several categories at once. For example, inspirational images can be related to a variety of projects. *Deferred location* concerns the spatial location of the artifact, which is an indicator for its category. No matter whether on the desktop or on the whiteboard, users create meaning by organizing space [50], as a mental image helps to understand the structural connections between different artifacts. For example, different piles on a physical desktop can represent different projects or priorities. Generating a mental image is also important in collaborative settings [58]. Therefore, it is particularly important that a design team has a shared understanding of the produced spatial layout. A computer system could provide *automatic classification* by using the information of its artifacts. For example, four heaps on different spatial locations may symbolize four different designers or a timeline illustrates the artifacts in chronological order. Nevertheless, for the automatic generation of a mental image, computers have mostly not enough information about the user's intentions. So, more interesting is that a system provides support for the process of spatially arranging artifacts. One essential requirement for supporting designers in this process is that they are not forced to categorize [1]. This would allow them to make spatial arrangements on their own and to create their own mental image of the artifacts.

3.1.3 Problems in physical and digital organization

The main difference between physical and digital organization of artifacts is that digital files and folders require titling. Getting an overview and finding artifacts again in this hierarchical titled structures can be hard. Finding an appropriate name for a file or folder could also be a challenge. As a consequence, the question is how to decide about the classification of information? Which categories should be created and what is their meaning?

On a physical desktop, less titled piles are common [40]. Filing is mostly made randomly, in alphabetical order or color-coded [41]. People have furthermore the freedom to create semantic groups either on their physical tables or on whiteboards. In the digital space, people are more constrained in the spatial arrangement of artifacts. Therefore, a system, which supports grouping tasks, should consider different spatial layouts as these are more flexible than tight groups [7] and can be additionally used for expressing relationships among artifacts [31].

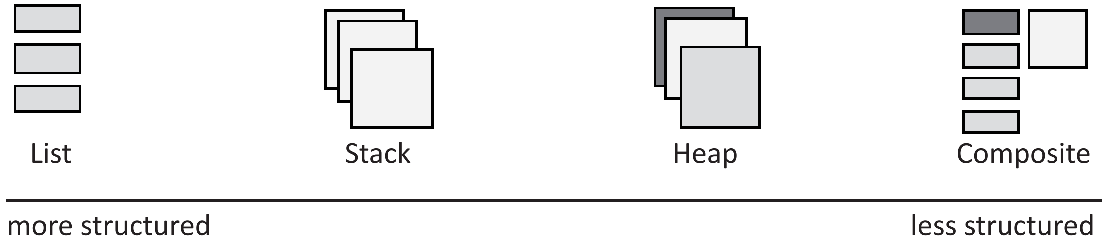


Figure 3.1: Primitive spatial structures [55] aligned to their amount of structure.

3.2 The range of spatial layouts

Humans arrange artifacts in a variety of spatial layouts. Depending on the purpose of the arrangement and the human's intention, these arrangements range from clearly structured and constrained to free and structureless. For example, humans preferred a grid layout as well as an overlap for organizing photographs [22], which are two completely different spatial structures. However, the most common spatial layouts are *lists*, *stacks*, *heaps*, *composites* [55]. Figure 3.1 provides an overview about the named spatial arrangements and shows their degree of structure.

Lists share common features across objects and have a clear alignment for all objects. Similar to lists are grids or simpler structures such as rows or columns. This spatial arrangement is generally a very constrained one. Semantic grouping is not possible by using this structure. However, grids are generally perceived as tidy and provide a good overview. A grid-layout can be used for comparing artifacts.

Stacks are compact and include only one type of artifacts. In contrast to grid layouts, the stack needs less space as objects can be stacked on each other. A disadvantage is that not all objects of a stack can be viewed at once. This makes the comparison of objects impossible.

A *heap* is the less structured version of a stack. Heaps allow to pile different types of objects. However, the disadvantage is the same as the comparison of two artifacts of a heap is difficult.

Composites provide a more flexible spatial arrangement. Superimposed objects and subpiles can be created inside a composite. Cluster is used synonymously for composite. In comparison to single piles, composites support a rougher categorization [31].

As introduced in Chapter 1, designers need some kind of formal organization for their shared surfaces. The artifacts of designers are mostly visual and inspire their design spaces. The purpose of these visual artifacts is not just of informative nature such as for reminding or categorizing information. The goal of supporting the organization of those surfaces is on the one side to help in creating mental images of artifacts and on the other side to enrich an environment, which can be used for generating flourishing ideas. Therefore, a less structured and flexible spatial layout, which still helps in orienting and finding artifacts again is indispensable.

3.3 Design Goals

The previous sections have shown that spatial layouts are important in order to create a shared understanding by organizing information or knowledge in the physical or digital space. As already depicted, human-organized structures can be categorized in four major categories: grid, stack, heap and composite. On the one side, the main goal of supporting designers in their environment is to allow them to organize their artifacts chaotically as to create a holistic picture of a group of artifacts (e.g. artifacts of one project). On the other side, they should be able to find their artifacts again to reuse these (see Section 2.6.4) and should not get lost in a landscape full of visual artifacts. Bringing the design space in relation to spatial arrangement, the following aspects should be taken into account, when designing a spatial structure for organizing design artifacts:

- Create a spatial structure as simple as possible in order to keep the focus on the content of the structure.
- Flexible boundaries nestle gently around a group of objects and help in representing a group.
- The adjustability of a spatial structure raises the controllability, but needs more effort from the user.
- Semantic grouping is necessary so as to create a mental image of a group of visual artifacts.
- A spatial structure should help in keeping an overview and finding artifacts again.

3.4 Spatial layouting in the digital space

Spatial layouts have long been used for managing artifacts on computers. Several tools were developed in order to support users in organizing information.

Robertson et al. [50] developed Data Mountain for organizing and arranging web pages. BrainDump [10], by Brade et al., focuses on information-gathering in the Web by using a zoomable interface.

Agarawala et al. [1] introduced BumpTop, a system, which adds physics to the desktop for a more continuous and analog interaction feeling. Jakobsen et al. [34] focused on piles, tabs and overlaps in the desktop environment. Bubble Clusters, by Watanabe et al. [61], is an interface for manipulating spatial aggregated objects such as icons on the desktop by using the bubble metaphor.

Dynapad, by Bauer et al. [6, 7], is a zoomable interface for exploring and organizing collections of digital photos or other media. Flux [8], PhotoHelix [28] and World of Information [33] are interfaces for organizing digital photo collections. Goto and Goto [21] developed Musicream, a novel music playback system.

Flatland is an early work of Mynatt et al. [43] for co-located informal use of whiteboards. The ART-system, by Nakakoji et al. [44], supports designers in the early phases of design by making use of reflection-in-action [51]. Designer's Outpost [36], Brainstorming System [29] and AffinityTable [18] are designed for supporting creative collaborative activities.

Storage Bins [52, 53] and Interface Currents [30] are interface component designs for investigating the tabletop workspace.

The following sections sum up already existing spatial structures. The focus is on those, which provide a visual boundary around a group of objects. This special type is called container in the following. Each section describes the design of a container and dedicates its purpose and application domain. Afterwards, the container type is discussed concerning the previous defined design goals: *simplicity*, *flexible boundaries*, *adjustable boundaries*, *semantic grouping* and *providing an overview*.

3.4.1 Data Mountain

Data Mountain is a system for freely arranging thumbnails in a 3D desktop environment by using 2D interaction techniques [50]. The information can be placed on several hills in the 3D space (see Figure 3.2a). If thumbnails are dragged, other pages move away. Detail-on-demand allows the user to view the whole document of a thumbnail. The main intention of this work is that storing a document in a spatial position improves the user's performance.

(a) (b)

Figure 3.2: DataMountain [50]: (a) Spatial arrangement of 100 web pages. (b) Overlappings as a consequence of detail-on-demand.

The third dimension of Data Mountain reduces the simplicity of the system. The hills on which information can be aggregated do not consider the content on the top and can not be adjusted. With Data Mountain, the user has one dimension more for grouping thumbnails, which could be an advantage. Anyhow, thumbnails were superimposed by each other, which is not really helpful for getting an overview. The detail-on-demand technique hides all objects behind the document in the front (see Figure 3.2b). This can help in focusing on the document, but in order to raise consistency all objects in the background should be hidden or blurred out.

The hills in DataMountain constrain the user in spatial arrangement as they are fixed-sized and could not be adjusted. The third dimension provides more space, but also adds complexity to the interface.

3.4.2 Flatland

Supporting informal use of whiteboards is the purpose of Flatland [43]. The interaction techniques of Flatland are executed by using a stylus on a whiteboard. Incoming strokes were automatically surrounded by a bounding box.

The bounding box adjusts its flexible boundaries by adding new segments. The user can not modify this boundaries. Superimposed objects are not allowed and objects shrink in order to provide more space. Concerning the grouping of objects, there is some discrepancy, as similar content could be kept together or the system automatically recognizes, for example lists, and arranges these. This could be one reason, why users would need some time for practicing before they were familiar with the system. But as the authors argued, the major goal of the system is to support long-term informal use.

3.4.3 Dynapad

Dynapad is an interface for managing personal information or photo collections [6,7]. This spatial tool is a zoomable interface and follows the line of Pad [46] and Pad++ [9]. Dynapad provides two different types of containers: *self-adjusting clumps* and *grid-layout trays* (see Figure 3.3).

(a) (b)

Figure 3.3: Dynapad [7]: (a) Self-adjusting clump. (b) Grid-layout tray.

A *clump* belongs to the group of composites. Objects wihtin a clump's boundary stick together and maintain their spatial position. By zooming out of the landscape, clumps fuse together, which provides a better overview. The usage of hierarchies adds complexity to this structure. A clump has self-adjusting boundaries. If objects were added, the boundary expands automatically. Figure 3.3a shows that a clump allows semantic grouping of objects inside the boundary. The boundary of a self-adjusting clump is a convex hull and could not be modified by the user.

In contrast to the clump, the *tray* is more constrained. The underlying spatial structure is a grid, which provides a much more better overview of the objects inside than a composite. Objects could be additionally arranged in a timeline. For sorting the objects, the system uses the metadata of the objects. A tray adapts its size to the number of objects inside automatically, but does not allow the user to adjust the boundary.

In short, trays are less controllable than clumps, but require also less effort from the user. The clump's underlying spatial structure are composites. A tray makes use of the grid and is simpler in its functionality, but a clump gives more freedom regarding spatially arranging objects.

3.4.4 Storage Bins

Storage Bins is a prototype system, which was originally developed to find out, how well this system supports tabletop territoriality and grouping of workspace content on a digital tabletop [52, 53].

(a) (b) (c)

Figure 3.4: Storage Bins [53]: (a) Dragging an object into a Storage Bin and resizing the object automatically [1]. (b) Storage Bin with originally arranged objects. (c) Collapsed Storage Bin.

A Storage Bin is a mobile adjustable container in form of an octagon. This form appears relatively complex, but one of the benefits is that users can adjust the boundaries of the shape by using handles on the eight corners. For providing a better overview, objects are resized by entering a Storage Bin in order to save space inside the Storage Bin (see Figure 3.4a). Figure 3.4b illustrates objects inside a Storage Bin. This group of objects can be collapsed, but can not be spread out again (see Figure 3.4c). This is an inconsistency in the design of this interface component and may confuses users.

In a nutshell, a Storage Bin is rather complex due to the eight handles for adjusting the shape but concerning the spatial arrangement, this container type gives a lot of freedom to the user.

3.4.5 Interface Currents

The reconfigurable and mobile tabletop interface components Interface Currents provide a controllable flow for various interface items such as pictures or documents [30]. Interface Currents is designed for digital tabletops and works with pen input. For managing interface items, Interface Currents provides three different structures: *Peripheral Currents*, *Stream Currents* and *Pool Currents* (see Figure 3.5).

Peripheral Currents are typically attached to the edges of the touch-sensitive surface. The purpose of this type is to provide an overview. As all other Currents, the user can draw the shape of the Current on his own, which gives more freedom to the user. The

[1] http://www.eng.uwaterloo.ca/˜s9scott/wiki/pmwiki.php?n¯Main.TabletopInteractionTechniques

(a) (b) (c)

Figure 3.5: Interface Currents [30]: (a) Peripheral current. (b) Stream current. (c) Pool current.

overview in peripheral Currents is pretty good as objects flow circular around the table (see Figure 3.5a). In this containert type, the size of the objects is adapted to the space at the flowing position instead of adjusting the Current's boundary.

For collecting objects, Interface Currents provide *Stream Currents*. The only difference to the Peripheral Currents is, that Stream Currents are typically positioned in the middle of the tabletop. Peripheral Currents dock to the edges of the tabletop.

Pool Currents are designed for storing objects temporarily. In contrast to Stream Currents, objects are not forced to flow in Pool Currents. The arrangement of objects is user-defined and belongs to the type of composites.

All of these structures look similar, but differ slightly in some aspects. Drawing and adjusting the shapes gives the user a great freedom in all three cases. Objects can be accessed equally from all users due to the flowing structure. However, the overview could suffer from that, as a user can easily loose track in this structure.

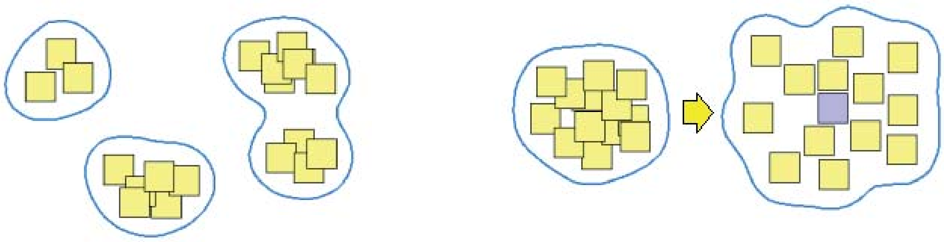
3.4.6 Bubble Clusters

Bubble Clusters is an interaction concept for managing loosely organized information such as icons or strokes in a 2D desktop environment and makes use of a mouse as input device. By using Bubble Clusters, spatially aggregated objects are automatically recognized as groups and surrounded by a contour.

As a composite, Bubble Clusters allows to group objects semantically. The user has not to care about the boundaries, as those are flexible and nestle automatically around the objects inside a bubble. One weakness is that boundaries can not be adjusted by the user. But this fact reduces the complexity and let Bubble Clusters be perceived as simple. In addition, the user can spread superimposed objects so as to get an overview, which is another advantage. Therefore, the surrounding contour adapts its shape automatically.

Bubble Clusters is a simple concept, which constrains the user in modifying the container shape, but adds functionality for example the spreading technique, which takes care of superimposed objects.

[2] http://www-ui.is.s.u-tokyo.ac.jp/~takeo/research/bubble/index.html

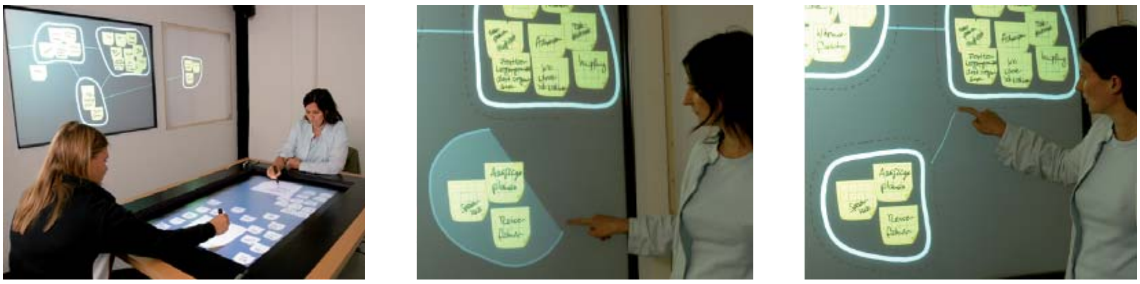


(a) (b)

Figure 3.6: Bubble Clusters [61]: (a) Spatial aggregated objects in bubbles. (b) Providing an overview by spreading objects.[2]

3.4.7 Brainstorming system

Figure 3.7 shows the wall display of a system for supporting collaborative creativity [29]. The whole system consists of a digital tabletop and a wall display. The focus is in the following on the grouping structure, which can be seen in Figure 3.7b and 3.7c.



(a) (b) (c)

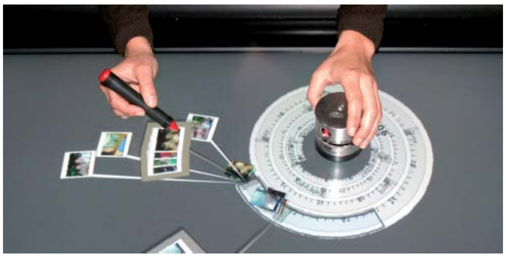
Figure 3.7: Brainstorming system [29]: (a) Setup consisting of a digital tabletop and wall display. (b) Creating a cluster. (c) Connecting two clusters.

The interactive wall of the brainstorming system allows to create a cluster by drawing a free-form stroke around some objects. Drawing a cross in the transparent region of the clusters removes it. The boundaries are not flexible. Once drawn, modifying is not possible. If two clusters collide, they will merge. For constituting relationships between clusters, the user can draw links between them. This can be used to highlight further connections in the information. Semantic grouping of objects is possible as these clusters belong to the group of composites.

This structure can be generally rated as pretty good. The only weaknesses are the removing technique and the constrained boundary, which can not be adjusted by the user.

3.4.8 PhotoHelix

PhotoHelix is a co-located interface for browsing and sharing digital pictures on an interactive tabletop [28]. For the interaction with PhotoHelix, a stylus and a physical token are used (see Figure 3.8a).



(a)

(b)

Figure 3.8: PhotoHelix [28]: (a) Spiral-shaped time-based visualization with its physical control and the pen as input device. (b) Organizing, navigating and sharing of pictures.

The complexity of PhotoHelix is due to the spiral-shaped interface. All objects are preordered and clustered in order to give some structure and save space. By using PhotoHelix, a user can define his own collections for viewing and sharing (see Figure 3.8b). The major problems of this interface are visual clutter, as objects are piled inside the spiral shape, and scalability, as more objects raise the complexity of this interface. In some cases, the time-visualization of PhotoHelix could be advantageous, as users can navigate through and focus on specific piles by spreading out all objects of a pile. One disadvantage is that the spiral does not allow any comparison between single time units.

In short, PhotoHelix is a complex system, which especially suffers from visual clutter and scalability.

3.4.9 Flux

Flux is an interface for organizing and sharing photographs on a digital tabletop [8]. To support this task, Flux provides three different structures: *workspace*, *pile* and *cluster*. The photo collection in the background is arranged in a simple grid, which is constrained to the boundaries of the tabletop. Figure 3.9a shows Flux for managing a photo collection.

Flux's *workspace* is a rectangular space, where objects can be temporarily stored (see Figure 3.9b). The boundaries of this space adapt to its content, but can not be adjusted by the user. Semantic grouping inside the workspace is possible.

Figure 3.9c shows a *pile*, which can be used for tidying up the background collection. This structure is simple, but one major problem is that objects can be superimposed. In the context of other piles, semantic grouping is possible (see Figure 3.9a), but user can not define their own spatial arrangements inside one pile.

A *cluster* in Flux is a user-created group, which typically has a name and a colored boundary (see Figure 3.9d). The color of this boundary can be modified by the user, for example, as to create different groups. The boundary itself nestles around all objects

(a) (b) (c) (d)

Figure 3.9: Flux [8]: (a) A photo collection in Flux. (b) Workspace. (c) Pile. (d) Cluster.

automatically. As a cluster belongs to the group of composites, objects can be superimposed and provide consequently less overview for the user.

Flux provides three structures, which are completely different. The workspace is used for storing pictures temporarily. A pile, as part of the background collection, but permits semantic grouping in the context of other piles. Clusters can be named and colored. The nestling boundary is flexible, but can not be adjusted.

3.4.10 BrainDump

BrainDump is a zoomable user interface (compare Pad [46], Pad++ [9], Dynapad [6, 7]) for memorizing and organizing information such as web content [10]. A tablet PC and a stylus are used as input devices (see Figure 3.10).

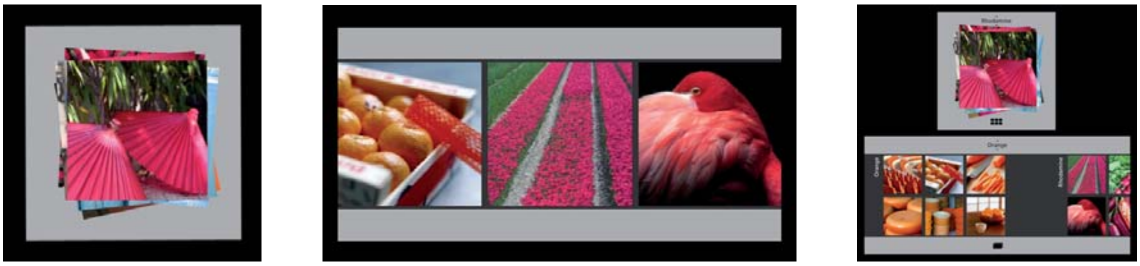
Figure 3.10: BrainDump [10]: an interface for visual information-gathering.

BrainDump follows the line of using the bubble metaphor (compare Section 3.4.6 and 3.4.7). The big difference is that BrainDump makes use of a hierarchical structure and adds consequently complexity to this simple metaphor. The problem of the zoomable landscape is that the user can get lost with the raising number of hierarchies. One advantage of this interface is the usage of composites as underlying structures. This allows the user to create his own spatial arrangement in the landscape. Furthermore, the proximity of objects could indicate the degree of relationship, which is another advantage for semantic grouping.

To sum it up, BrainDump is a good approach for organizing a landscape, the only weakness is the hierarchical layout.

3.4.11 MS Surface 2.0 SDK

The Microsoft Surface 2.0 SDK[3] makes two kind of library controls available, each representing a container holding a collection of objects. These controls look smart, but provide less flexibility to the user.



(a) (b) (c)

Figure 3.11: MS Surface SDK: (a) LibraryStack. (b) LibraryBar. (c) LibraryContainer for changing between bar and stack view by touching a button.

According to Figure 3.11a, a *LibraryStack* is a pile with a surrounding boundary. The stacked objects can not be viewed at once, which means that getting in overview is hard for the user. This structure does not allow the user to make its own spatial arrangement inside the container. Furthermore, the boundary of this control is whether flexible nor adjustable.

Figure 3.11b shows a *LibraryBar*, which belongs to the more structured grid respectively row layout. Concerning the boundaries and the semantic grouping of objects, the problems are the same as for the first control type. More advantageous is the grid layout, which supports the user in getting an overview.

Both of these structures are very constrained and give less freedom to the user. The *LibraryContainer* shown in Figure 3.11c is combination of both controls and allows the user to switch between the visualizations. Nevertheless, these controls look simple and would sometimes be enough. For example, a *LibraryBar* can be used for the comparison of objects and a *LibraryStack* can furthermore serve as temporary storage medium.

3.5 Summary

In this Section, the use of spatial layouts was introduced. The reasons for organizing information and knowledge either in the physical or in the digital space are various. Malone [40] defined two major reasons for desk organization: reminder and organization. Even the visibility of artifacts reminds people on things to do. Reminding can happen by instance, context or structure. Reminding is still a topic either in physical or digital space and could be supported by computers. The biggest difference between categorization in physical and digital space is that files and folders on a computer require titling. On a physical desktop, piles are loosely arranged without any exact title. The problem with titling of files on a computer system is that names should be remembered in the re-finding process. Another

[3] http://msdn.microsoft.com/en-us/library/ff727879.aspx

issue is how to decide about the names of categories and what is the meaning of those names?

Spatial layouts are more flexible than tight groups [7]. The range of human-organized layouts ranges from clearly structured to completely unstructured. Shipman et al. [55] defined four different spatial layouts: lists, stacks, heaps and composites. The goal of using spatial layouts in the design space is to help designers in creating mental images of their artifacts and to enrich their environment with visual artifacts for producing flourishing ideas.

Table 3.1: Different types of containers and their degree of being simple, providing flexible or adjustable boundaries, supporting semantic grouping and providing an overview.

Type	Simplicity	Flexible Boundaries	Adjustable Boundaries	Supports Semantic Grouping	Provides an Overview
DataMountain	*o*	−−	−−	++	-
Flatland	*o*	++	−−	*o*	++
Dynapad (clump)	*o*	++	−−	++	+
Dynapad (tray)	+	++	−−	−−	++
Storage Bin	+	*o*	++	++	*o*
Interface Currents (peripheral current)	+	++	++	−−	++
Interface Currents (stream current)	+	++	++	−−	++
Interface Currents (pool current)	+	++	++	++	+
Bubble Clusters	++	++	−−	++	++
Brainstorming System (cluster)	+	++	−−	++	*o*
PhotoHelix	−−	−−	−−	+	-
Flux (workspace)	++	−−	*o*	++	+
Flux (pile)	++	−−		++	*o*
Flux (cluster)	++	++	*o*	++	*o*
BrainDump	-	+	−−	++	-
MS Surface 2.0 (LibraryStack)	+	−−	−−	−−	−−
MS Surface 2.0 (LibraryBar)	+	−−	−−	−−	++

Five design goals were defined in order to create an appropriate spatial layout for organizing visual artifacts. These goals concern the simplicity of the spatial layout, the flexibility and adjustability of the surrounding boundary, the support of semantic grouping and providing an overview. Eleven different systems and 18 spatial layouts were analyzed regarding these aspects. Table 3.1 provides an overview of all these structures with the amount of support in each category. LibraryStack and PhotoHelix [28] have on average the worst rating. The first one is too constrained and provides less functionality. The second one is a rather complex system, which needs some practice and skill and would not be appropriate for the designer's organization of visual artifacts. The best spatial layout provides Interface Currents [30] with the Pool Current. Only the simplicity is a little down-rated. An Interface Current can be drawn and adjusted by the user. In contrast to that, a little bit simpler is a Storage Bin [52, 53] as handles are pre-defined and the user can adjust the container by using these handles. Bubble Clusters [61], as only system, provides an overview and allows semantic grouping at once. The reason therefore is the spreading technique, which can be used for expanding superimposed objects.

Flux's cluster [8], Storage Bins and Bubble Clusters were on average equally rated. All of this layouts belong to the group of composites, which is appropriate for the organization of the design space. Designer's need freedom in arranging their visual artifacts. Bubble Clusters may have potential to support the arrangement of visual artifacts on a digital tabletop because the idea behind is simple and easy to understand. One reason therefore is that the bubble metaphor is bionically inspired and adds some physics to the system. Flux's cluster is pretty similar to Bubble Clusters and makes a more constrained impression as the boundaries were directly nestled to the objects. Storage Bins is different to Bubble Clusters as the strengths and weaknesses are differently divided. In contrast to a Bubble Cluster, a Storage Bin has adjustable boundaries, which adds a greater level of flexibility to the user. In the following, these concepts are the foundations for Blub and Bin, which are interfaces for organizing visual artifacts on a digital tabletop.

Chapter 4

Design Rationale

This chapter focuses on the interaction concept behind Blub and Bin. The main issue of both concepts is to support users in organizing visual artifacts. Grouping is an essential concern in order to create composites as introduced in the last chapter. The current suggested techniques for selecting a group of objects on a digital tabletop are sequential tapping or encircling of the preferred objects [17,63]. The appliance of similar techniques is described and analyzed in the following as to emphasize why Blub is a potential candidate for supporting the organization of visual artifacts.

The first technique, Pick-and-Drop [49] is designed for transferring simple artifacts (e.g. icons, images) between computers or other electronic devices such as PDAs. Therefore, the user picks up an object from one display and drops it on the other display (see Figure 4.1). Typically, this interaction technique is executed with a pen. AffinityTable [18], for example, applies this technique by using a physical token. The main advantage of this technique is, being especially suitable for spatially distributed objects across large displays or tabletops, as dragging an object diagonal across the table would be exhausting. The original spatial relation between multiple picked up objects does not remain, which can be a disadvantage for a grouping task. For example, AffinityTable preserves the rotation of the artifacts, but pushes them directly on a pile. Arranging these artifacts again needs some additional effort. So the question is if there is a way to sustain the original relative position between artifacts or to provide the relationship between objects?

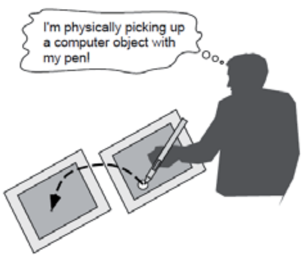


Figure 4.1: Pick-and-Drop [49]: Picking up an item and dropping it on another display.

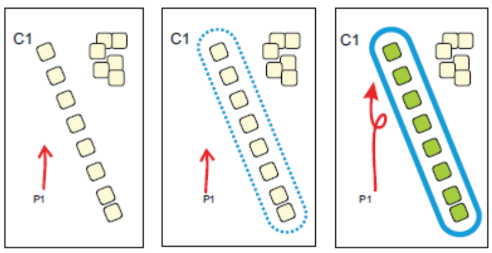


Figure 4.2: ICE Lasso [14]: Initiating a lasso selection, predicting an ICE path and performing a pigtail gesture.

The second selection technique is the ICE-Lasso. This technique is designed for selecting partial, complete or multiple clusters by using a graphical tablet. Figure 4.2 shows the three stages of interaction. The user initiates the lasso and the system predicts an ICE path. Finally, the user selects this group by performing a pigtail gesture. According to Dehmeshki [14], users perform faster by using the ICE-Lasso than by encircling objects in cause of shorter drawing distances. This technique is easy to learn and to use and furthermore enables to select multiple clusters at once. One disadvantage of this technique is, that the visual boundary is removed after moving the selection, which means that groups have to be selected again and again for new dragging operations.

Pick-and-Drop as well as ICE-Lasso are not the best solutions for organizing visual design artifacts. Pick-and-Drop is an easy understandable technique but picked and dropped objects do not preserve their relative position to other objects. The ICE-Lasso enhances the selection task but the problem is that selections are not maintained. So groups have to be selected again and again for new movements. To give some more flexibility to designers so as to spatially arrange visual artifacts, the next sections introduce Blub and Bin, two interfaces for object and group manipulation on digital tabletops.[1]

4.1 Blub

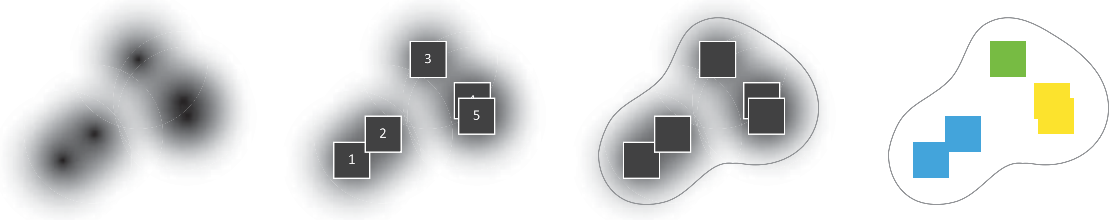
This chapter describes the ideas behind the visualization and the interaction techniques of Blub. A short introduction to the underlying principle is given in the beginning. The visualization as well as the interaction techniques are discussed and competitive work is shown afterwards. The gestural design is disputed in order to outline the reasons for the usage of specific gestures.

4.1.1 Idea

Blub is the approach to bring the existing interaction concept of Bubble Clusters [61] from the desktop to touch-sensitive surfaces. The idea behind Blub is to support object and group manipulation on digital surfaces by the use of flexible interaction techniques. Therefore, each object is surrounded by a bubble. A bubble is a kind of container, which dynamically adjusts its shape according number and positions of objects in it. A bubble has an $1 : n$ relationship as at least one object belongs to a bubble. The foundation of Blub lies in the *Gestalt law of Proximity* [56].

The *Gestalt law of Proximity* mentions that humans perceive elements, which are close together as a group or even more related. Connected or overlapping elements are usually interpreted as sharing one or more common attributes. In contrast to that, proximal, but not-contacting elements are construed as related, but independent. This Gestalt law has great effect on human's perception as it overwhelms other principles like similarity [38].

[1] Algorithms and implementation details can be found in the corresponding technical report to the Master's project.



(a) (b) (c) (d)

Figure 4.3: Blub Visualization: (a) Force fields of objects. (b) Force fields and objects. (c) Force fields, objects and visual boundary. (d) Final representation of a bubble.

4.1.2 Visual Representation

Figure 4.3a shows the underlying physical structure of a bubble. Each object has its own force field. Illustrated by the gradient, energy decreases from the center to the edge of the force field. Objects such as 4 and 5 are perceived as stronger related, which is strengthened by the merged force fields in Figure 4.3b. In opposite to that, 3 has a larger distance to 1 and 2. This could mean that 3 is related, but shares less attributes with them. Intersecting force fields are merged and surrounded by a contour in order to intensify the perception of a group (see Figure 4.3c). Force fields are not rendered in the final representation so as to avoid visual clutter as illustrated in Figure 4.3d.

The visual representation of Blub belongs to the spatial layout type of composites (compare Section 3.2). This facilitates semantic grouping inside a bubble, for example, to express relationships between objects. On the one hand, the surrounding boundary intensifies the visual perception of the bubble as a group, which is an advantage. On the other hand, this boundary adds visual clutter to the visualization. Anyhow it is important that the size of the surrounding force field and consequently the nestling boundary is appropriate to the purpose and the amount of artifacts shown on the display.

4.1.3 Interaction Techniques

Besides the visual representation of a bubble, Blub provides various possibilities for interaction. In the following, these interaction techniques are called: *Group by object*, *Group by bubble*, *Splitting a bubble* and *Spreading objects*.

The following sections are structured as follows: First, the principle of the interaction technique is explained on base of figures and a short guide of practice is given. Then, reasons for the interaction design are highlighted and the interaction technique is compared to other techniques.

Group by object

Two bubbles will melt together, if they are colliding. Figure 4.4 shows the general procedure for a user to create a group by dragging objects.

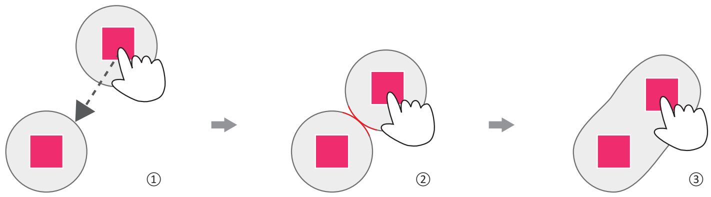


Figure 4.4: (1) Dragging an object. (2) Touching boundaries. (3) Melting of bubbles.

The user starts by touching an object. To move the object and the surrounding bubble, the user slides the finger with the object underneath to the desired position. If the bubble touches another bubble, they will melt together. To pull an object apart from a bubble, the user touches the desired object and slides it over the surface to the desired position. As soon as the object is sufficiently far from the bubble, the object get its own surrounding bubble.

Colliding bubbles run seamlessly one into one by dragging an object. This is bionically inspired by merging water drops (see Figure 4.6) [10]. Grouping by object is based on the *Gestalt law of Unity* respectively *Uniform Connectedness* [56]. This means, that visually connected elements are perceived as more related than elements without a connection. In accordance with Lidwell et al. [38], this design principle overpowers all other Gestalt laws. In the case of Blub, the proximity between objects is strengthened by the surrounding bubble contour.

One of the big advantages of this technique is that users get direct feedback while dragging an object. The distance between two objects determines the visualization of the boundary as objects with larger distances have a weaker bubble connection than superimposed objects. This representation furthermore allows the user to make individual groups inside a bubble in order to emphasize different relations between objects.

Group by bubble

A bubble is a kind of storage medium, which can be used to transport one or more objects. Figure 4.5 demonstrates this interaction technique.

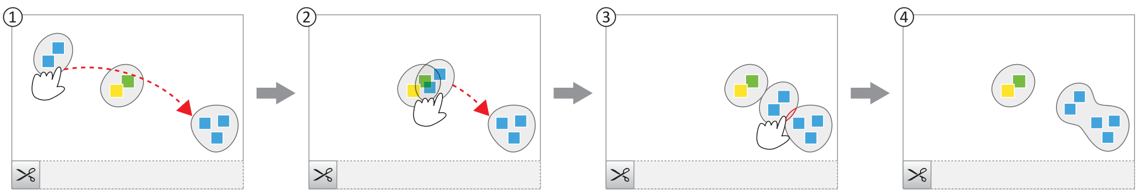


Figure 4.5: (1) Touching a bubble. (2) Dragging a bubble over objects. (3) Releasing bubble on the desired position. (4) Merging of bubbles.

The user has the option to group by bubble, which means that one or more objects can be moved in a bubble to any position on the surface. The user touches the bubble with one or more fingers and drags it to the desired position. As long as the bubble is moved, bubbles do not automatically merge. If the user takes his fingers away, the bubble merges with bubbles underneath.

In contrast to the group by object technique, the bubble is used as a transport medium for objects. Looking into the real-world, this can be compared with soap bubbles. Figure 4.7 shows three soap bubbles, which are attached to each other. Some of them may merge after a few seconds before they explode. This can be compared with the dragging of bubbles in the Blub interface. As long as a user moves a bubble, it does not merge with any underlying bubbles. If the bubble is released, bubbles will melt together. In a 3D environment, this could also be seen as lifting and dropping a bubble.

This technique is particularly appropriate for target-oriented operations. During the dragging operation, the system does not consider other bubbles and the user can focus on his operation. This could also be a disadvantage, as the user does not get any feedback from the system until he drops the bubble. But as the user wants to transport multiple objects at once, this will be suitable for his intention. In opposite to the *Group by object*, multiple objects can be dragged and grouped, which saves a lot of time, which is a main advantage.

Figure 4.6: Group by object: Water-drops metaphor[2].

Figure 4.7: Group by bubble: Soap bubble metaphor[3].

Splitting a bubble

A hand-drawn free-form-stroke is capable of splitting a bubble. Figure 4.8 illustrates the procedure for this interaction technique.

The user pushes the scissor button on the bottom left corner of the interface and runs one finger across the bubble, which should be split. If the finger is taken away, the bubble will split and two new bubbles move apart from each other.

The usage of a button for changing the mode is a first approach in order to use this gesture in a zoom- and pannable interface. Nevertheless, this current design has some drawbacks. The fixed positioned button is more suitable for single-user than for collaborative settings. An alternative to the button is a physical token, which could be used to switch the mode. The advantage is that the appliance of a token is not constrained to a specific position. However, the problem with collaborative settings remains, as the use of

[2]http://blog.mogomoney.com/wp-content/uploads/2010/08/Blue-Ice-Water-Drops-TLG.png
[3]http://3.bp.blogspot.com/-wAIwP5kT18o/Tfwg5E0_5eI/AAAAAAAAB-U/leQ7cIChh6I/s1600/Soap_bubble_3_RGB.png

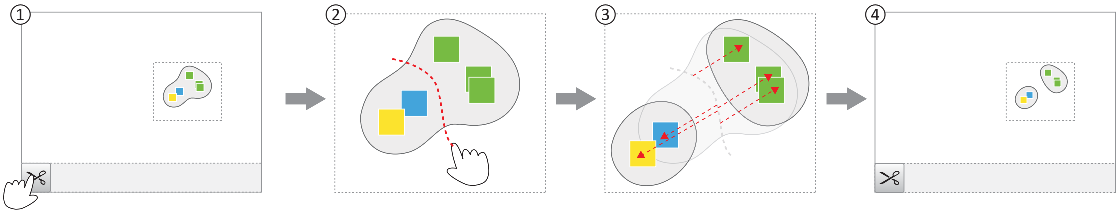


Figure 4.8: (1) Pushing the scissor button. (2) Drawing a stroke. (3) Moving bubbles apart from each other. (4) Result.

a physical object could also interrupt other users in their interaction. One more possibility is to mark regions, where only splitting operations are allowed. If these regions are movable, these splitting regions will improve the interface. However, this alternative adds more visual clutter to the interface, as these regions consume valuable space and can only be used for splitting operations. Introducing some kind of mode switch is pretty hard as every alternative has advantages and disadvantages. As users have experience in using buttons (e.g. desktop applications, websites), mode switches in the Blub interface are realized with buttons.

In accordance with the gesture guide of Wobbrock et al. [63], a cut gesture is used so as to split a bubble. To support more creative cuttings, the user is able to draw a free-form stroke instead of a common line.

Adding physics enriches the interface with a more realistic feeling [1]. This is the reason why bubbles move smoothly apart. Another benefit is that the operation is perceived as continuous and gives more feedback to the user. And not least, if new bubbles do not change their positions after a splitting operations, bubbles will merge again too easily and this interaction technique would be obsolete.

Spreading objects

To avoid overlapping objects in a bubble, objects can be spread inside a bubble. Figure 4.9 shows how this works for the user.

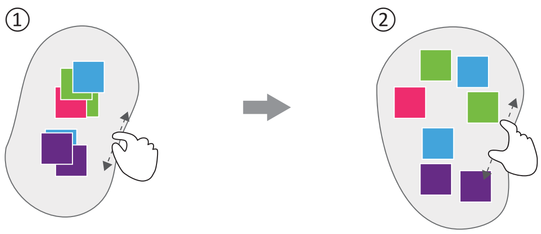
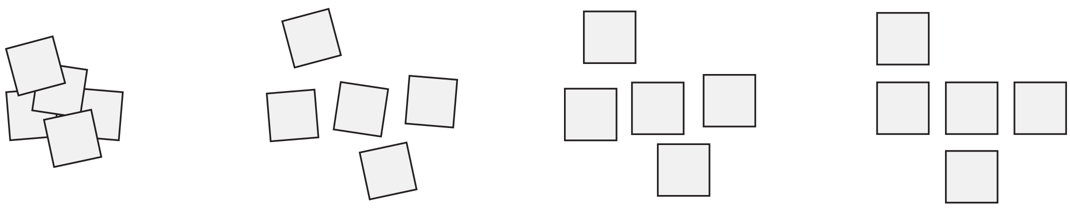


Figure 4.9: (1) Placing two fingers in the bubble space. (2) Pulling them apart.

The user is able to spread superimposed objects through placing two fingers (e.g. thumb and index finger) directly on the bubble and pulling them apart. The objects are animated to their new positions and the bubble adapts its surrounding contour. Afterwards, all objects stay in their new position and can not be returned to their old positions.

According to Wobbrock et al. [63], pinching is a typical gesture for resizing an object. By executing this gesture, two fingers move apart. Comparing this with spreading objects, the gesture and the goal are similar as objects should move apart so that no overlappings are preserved. This is the reason for assigning this gesture to the spreading operation. The result of spreading are distributed objects. Figure 4.10a shows a heap of superimposed objects. There are several possibilities for the visualization of spreaded objects (compare [1, 2, 64]). Design Variant 1 (see Figure 4.10b) is the easiest way as objects only unblock each other in order to avoid overlappings, the rotation of each object stays the same. By the usage of Design Variant 2 (see Figure 4.10c) objects drain away and loose their original orientation. In Design Variant 3 (see Figure 4.10d), a grid aligns all objects. This can be compared with the *gathered clump* in Dynapad [7]. Figure 4.9 shows that the flexible layout is lost in ascending order of the design variants. Most beneficial in Design Variant 1 is, that most of the original information is maintained. This is important for the organization of visual artifacts as the relative position to other objects and the rotation of an object may provide essential information. Hence, Design Variant 1 is the visualization of choice.



(a) **(b)** **(c)** **(d)**

Figure 4.10: Design Variants: (a) Superimposed objects. (b) Distributed objects with original orientation. (c) Distributed objects with a new orientation. (d) Distributed objects aligned to a grid.

Animations are important for giving feedback to the user, as already argued in the last section. The reason for not moving the objects back into their original position is that this technique should just help to get an overview. The user may want to move objects apart from the distributed objects. If all objects move back to their original position, users might be confused as they are already one step further at that time.

The main drawback of this technique is that parts of the original spatial layout get lost. Nevertheless, spreading objects is a good technique for getting an overview and helps the user to find hidden objects again.

4.2 Bin

This chapter delineates the ideas behind the visualization and the interaction techniques of Bin. In the next sections, a short introduction to the underlying principle is given, the visualization as well as the interaction techniques are examined, competitive work is shown and the gestural design of each interaction technique is discussed.

4.2.1 Idea

Bin is based on Storage Bins [52,53], an interface for storing objects on a digital tabletop. A Storage Bin is a mobile, adjustable container, which enables the user to store and retrieve workspace content. The underlying principle of Bin is the *Container Image Schema* [32]. Humans have experience in using containers. For example, items can be stored in boxes (see Figure 4.11) or the human body can be experienced as object in a room or house, which can be categorized as container. Figure 4.13 illustrates that there are only two possibilities for an object in relation to a container, a object can be either inside or outside the boundary such as physical objects are either in a box or not. In contrast to a bubble, a bin has a $0 : n$ relationship as it can be empty.

Figure 4.11: *Container metaphor*: Storing objects in boxes.[4]

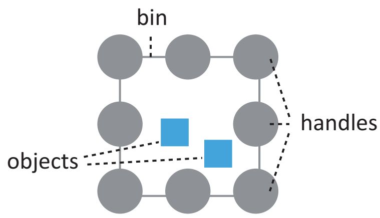


Figure 4.12: Bin with two objects.

The *Container Image Schema* is constantly present and easy to understand for humans. The current question is, what is about empty bins? Should they be removed automatically? Empty bins consume valuable space, which could be disadvantageous for this interface. Nevertheless, one of the benefits is that containers provide a concrete relationship to objects, as an object is either inside or outside a container. Furthermore, objects can be freely arranged inside a container and are not constrained to a specific layout, which would be convenient for a designer's organization task.

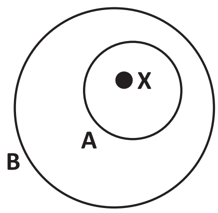


Figure 4.13: *Container Image Schema* [32]: X inside A inside B.

Figure 4.14: *Source-Path-Goal Schema* [32]: Bringing the source A to the destination B.

[4] http://www.tcbulk.com/ProdImages/MillerHobby/Large/ShortComicStorageBox.jpg

4.2.2 Visual Representation

A bin is a special kind of container. As Figure 4.12 illustrates, a bin has eight handles. These handles can be used for adjusting a bin's shape and consequently adding or removing space to or from a bin. To do so, the user simply drags one of the handles to a specified position. In contrast to a bubble, a bin's shape is more complex, but gives the user more freedom. The adaption of a bin's shape can be time-consuming, but otherwise, for example, a large empty space inside a bin could have specific meaning such as some artifacts are currently missing. So, the increased complexity can be good, but does not have to be.

4.2.3 Interaction Techniques

Bin provides the following interaction techniques for storing and retrieving objects in or from a bin: *Dragging objects into a bin*, *Collecting objects*, *Adjusting a bin*, *Selecting and moving objects* and *Spreading objects*.

The following sections are structured as follows: First, the principle of the interaction technique is described on base of figures and a short guide of practice is given. Then, reasons for the interaction design are given and the interaction technique is compared to other techniques.

Dragging objects into a bin

To add an object to a bin, a user can drag it into a bin. Therefore, the user has two options.

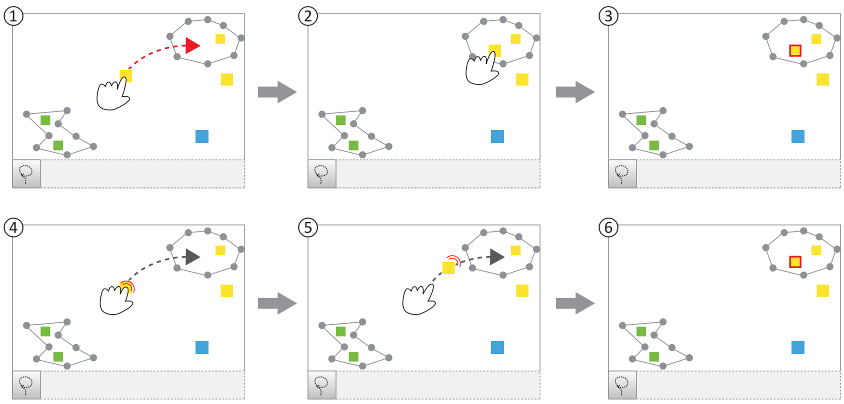


Figure 4.15: (1) Touching and dragging the object. (2) Releasing the object. (3) Resizing the object in the bin. (4) Tossing the object. (5) Object moves. (6) Holing the object into the bin.

The first option is touching and moving objects directly into a bin (see Figure 4.15-(1-3)). The second option is to use physicality. Therefore, an object is tossed towards a bin and begins to move. As it stands still in a bin, it gets holed (see Figure 4.15-(4-6)).

Users can drag objects directly into a bin. The underlying principle of this technique is the *Source-Path-Goal Schema*, which is shown in Figure 4.14 [32]. This schema consists of a source point, an end point and a vector in between. In this case, the dragged objects are the source and the bin is the goal. The dragging operation itself is the action path.

This technique can be compared with putting or throwing things into a box. The gesture is a simple dragging operation, which can be easily applied by the user. One disadvantage of this technique is, that dragging objects over large distances can be exhausting. Therefore other pick-and-drop techniques [49] in combination with tapping for selection would be more appropriate [63]. And what about multiple objects? As this technique is executed on a digital tabletop, all fingers can be used for moving objects into a bin, which allows one user to bin ten objects in parallel.

Collecting objects

Dragging and releasing a bin can be used for collecting objects.

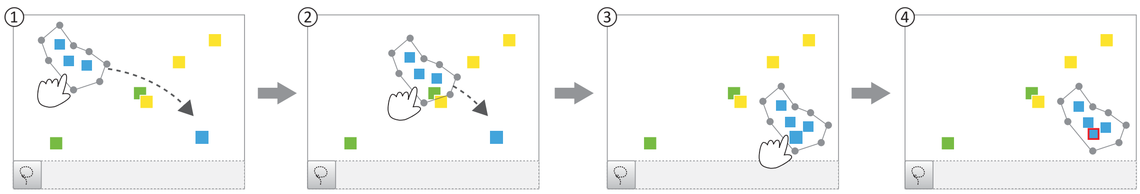


Figure 4.16: (1) Touching the bin. (2) Dragging the bin. (3) Releasing the bin. (4) Binning and resizing the object.

Therefore, the user first touches the bin. Then, he slides his finger to the desired object. If the bin is released, all objects, which are completely under the bin, will be collected at once.

Collecting objects is the vice versa technique to dragging objects into a bin. So, the *Source-Path-Goal Schema* can be called *Goal-Path-Source Schema* for this technique as the aim is to add objects to the bin and not the other way around. That is why objects are still the source and the bin is the goal. Figure 4.17 shows this reversed principle.

Figure 4.17: *Goal-Path-Source Schema* (Reversed *Source-Path-Goal Schema* [32]): Bringing the destination *B* to the source *A*.

This technique resolves one problem of dragging objects into a bin as the position of objects remains unchanged while these are collected by the bin. Another advantage is that a single user can add ten objects[5] to a bin at once. As this and the previous technique are mutually supportive, a combination of *Dragging objects into a bin* and *Collecting objects* provides a great functionality.

[5] *Ten objects* because a human has ten fingers.

Adjusting a bin

Another possibility to add an object to a bin is to adjust the bin by manipulating one of the eight handles.

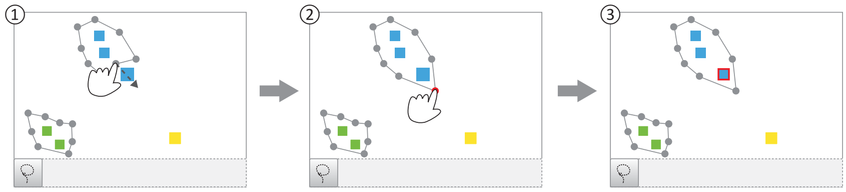


Figure 4.18: (1) Touching and dragging the handle. (2) Releasing the handle. (3) Resizing the object in the bin.

To adjust a bin, the user touches one of the eight handles with a finger and drags this handle to a desired position. As the handle is released by the user, the system checks, whether there is any new object directly under the bin. If this is the case, the object will be collected.

A bin can also be seen as a fenced field. For this, the handles would be pegs and each edge in between can be described as extendable band. To expand the field, the pegs can be displaced. For example, if a peg of a real plot is moved, new plants or some more stones can be either inside or outside the fence. The same principle is applied by using this interaction technique.

Adjusting a bin is especially helpful in order to maintain the original position of objects. Again, this technique makes use of the *Source-Path-Goal Schema* vice versa, which is called *Goal-Path-Source Schema* now, as the objects are the source and the bin is the goal. Totally, eight handles can be used in parallel for adapting the shape of a bin. This could speed up the grouping of objects as the bin's shape can be expanded into several directions at once. Anyhow, this technique will need some practice as the parallel handling of eight handles is hard to coordinate. In long-term use, this technique could be a promising, as it gives much more freedom to the user

Selecting and moving objects

To drag multiple objects, a selection tool allows to move several objects at once. How this tool is used is shown in Figure 4.19.

The user pushes the lasso button on the bottom left corner of the touch-sensitive surface and draws a fee-form selection shape. Then, the user drags the selected objects, which are completely covered by the selection geometry, to the desired position (e.g. into a bin). As soon as the user takes his fingers away, the system checks all bins regarding new object-bin relations.

The reasons for using a button as activator for a tool can be found in Section 4.1.3. The underlying principle for the further procedure of this technique is almost the same as for dragging objects into a bin. The components of the *Source-Path-Goal Schema* are the selected objects as source and the target bin as goal.

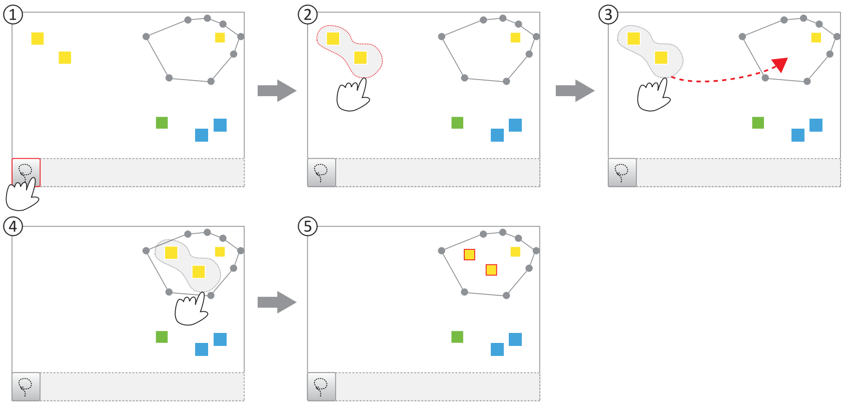


Figure 4.19: (1) Pushing the lasso button. (2) Drawing a selection. (3) Touching and dragging the selection. (4) Releasing the selection. (5) Resizing objects and removing the selection.

This technique is especially interesting for transporting multiple objects to or from a bin or just in order to move objects across the touch-sensitive surface. Convenient is, that spatial relations between selected objects remain unchanged. Nevertheless, one weakness is that this technique is relatively expensive in contrast to the other techniques, as the tool has to be activated and the selection has to be drawn before objects can be moved. Alternative selection techniques were shown in the introduction of this chapter. Pick-and-Drop [49], respectively selecting objects by tapping them sequentially [63], may be suitable for a small number of objects, as the relative position between objects gets lost by using these techniques. The other option is to use pigtail gestures [14] instead of encircling objects. As this Bin interface provides already a lot of different functionalities, gestures should be kept as tight and simple as possible, consequently the pigtail gesture was no alternative for selecting groups. Intelligent Object Group Selection [15] makes use of *Gestalt laws of Proximity* and *Good Continuation*. Spatial aggregated or arranged objects on a imaginary path are automatically recognized and suggested by the system. Then the user can confirm this selection. For arranging visual artifacts and maintaining their relations, this technique will not be appropriate. The user is too constrained, because selecting subgroups is hard and the interaction technique is rather complex. So, a common lasso tool, which allows to draw a free-form selection, seems to be the right choice for supporting the selection of multiple objects in the Bin interface.

Spreading objects

To avoid overlapping objects in a bin, objects can be spread inside a bin. The main difference to Blub's spreading technique is that the bin's boundary stays the same and does not automatically adjust to the objects inside. Figure 4.20 illustrates this operation.

Spreading objects is not a specific interaction technique of Bin. Section 4.1.3 has already covered the reasons for expanding objects, the various design variants for spreaded objects and the advantages and disadvantages of this interaction technique. In contrast to the bubble's flexible boundary, a bin's boundary remains unchanged by spreading objects. This

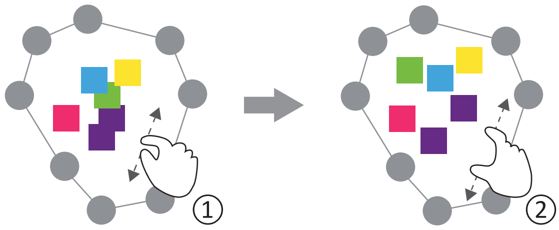


Figure 4.20: (1) Placing two fingers on the bin. (2) Pulling them apart.

is one of the weaknesses of Bin as user might be confused, if objects are excluded from the bin after they have been moved to new positions. The fundamentally related concept of Bin, Storage Bins [52, 53], does not provide any technique for getting an overview. Storage Bins facilitates the reversed way, as objects can be stacked by applying a gesture. The problem is that objects can not be expanded again and the relative positions get lost. The previously defined design goals (see Section 3.3) have depicted that getting an overview is an important issue in organizing visual artifacts. This is the main reason for designing this technique vice versa.

4.3 Summary

This chapter presented the Design Rationale of Blub and Bin. Before, some alternative approaches have been analyzed concerning their appropriateness in supporting the grouping of visual artifacts. Pick-and-Drop is an interaction technique for picking up objects on one position or display, and dropping them on another position or display [18, 49, 63]. The big disadvantage of this technique is that spatial relations between objects get lost. This is the reason why this technique is not suitable for enhancing the process of arranging visual artifacts. The second technique, ICE Lasso, is an alternative approach for selecting objects. The main advantage of this technique is that drawing paths are reduced by applying this technique [14]. Therefore the system automatically recognizes spatially aggregated objects as a group and suggest those for selection. The major problem of this interaction technique is that the system also constrains the user in his selection behavior as selecting spatially distributed objects is exhausting by using this technique. The three stages by applying this technique make the ICE Lasso rather complex.

Blub and Bin are two interfaces for supporting object and group manipulation as well as spatially grouping objects on digital tabletops. Table 4.1 shows both concepts in comparison to their base concepts Bubble Clusters [61] and Storage Bins [52, 53].

Blub is a simple, easy-to-use interface, which foundations lie in the *Gestalt laws of Proximity* for recognizing spatial aggregated objects as groups and the *Gestalt Law of Unity* for encircling a group. There are no big differences concerning the design goals in contrast to the original work of Bubble Clusters. However, Bubble Clusters was developed and designed for mouse input and Blub's goal is to support spatial arrangement on digital surfaces. Therefore, some interaction techniques were adapted for the task (e.g. Group by bubble) and suitable gestures were assigned to the different operations. The Blub interface

Table 4.1: Base concepts in comparison to Blub and Bin and their degree of being simple, providing flexible or adjustable boundaries, supporting semantic grouping and providing an overview.

Type	Simplicity	Flexible Boundaries	Adjustable Boundaries	Supports Semantic Grouping	Provides an Overview
Bubble Clusters	++	++	−−	++	++
Storage Bin	+	*o*	++	++	*o*
Blub	++	++	−−	++	++
Bin	*o*	+	++	++	++

can be perceived as physical and gives a natural feeling to the user by applying the bubble metaphor as colliding objects merge. Objects can also be tossed across the surface, which shows that Blub is a more playful approach. Grouping objects semantically is still possible and by applying the *Gestalt law of Unity*, spatial aggregated objects inside the bubble would be perceived as subgroups in a cluster. By pulling two fingers apart, superimposed objects can be spread and the user gets an overview. Therefore, the boundary adjusts automatically. The only disadvantage of Blub is that boundaries can not be modified by the user. Nevertheless, this could also be a benefit, as it reduces the complexity of interaction.

Bin's underlying principle is the *Container Image Schema*. Two interaction techniques of Bin make use of the *Source-Path-Goal Schema*. For two other techniques, this schema can be applied vice versa as *Goal-Path-Schema*. Humans are used to these principles as putting things into boxes is a common task in real life, which should result in an easy usage of Bin. The visual representation of a bin provides a possibility to adjust its boundary, in contrast to a bubble. This means more choice of freedom for the user, as free spaces in a bin can also have a meaning. Nevertheless, adjustable boundaries add more complexity to the interface. The objects inside a bin can be freely arranged, which means that semantic grouping is possible. Contrarily to the original Storage Bins, the Bin interface allows the user to get an overview of all objects inside a bin. This can be done by applying a pinching gesture like in the Blub interface. The difference is, that boundaries do not automatically adapt to its content again. So objects can drop out by executing the spreading technique, which will be a disadvantage.

Blub and Bin are both interfaces, which could have potential to support the organization of visual artifacts in a designer's environment. The next chapter presents a user study which compares the two interfaces in a simple grouping task. The main goal is to find out if the concept of Blub works on digital tabletops.

Chapter 5

User Study

To find out, if Blub works on digital tabletops and can be understood by the users, a user study was conducted. To measure the success of Blub in the grouping task, different data sources were chosen. The task completion time and different operations were logged in order to get information about the user performance and the different interaction types. To get an impression of the user experience, participants filled out two questionnaires and were asked about their preferences in a final interview.

The study is a replication of an icon grouping study by Watanabe et al. [61]. Their goal was to find out, if the interaction concept of Bubble Clusters helps users with icon grouping in a desktop environment. The following study investigates, if Blub, which is mainly based on Bubble Clusters, is appropriate for a grouping task on a digital tabletops. So the main difference to the original study is the input device. The major intention of Blub is to support the organization of visual artifacts and not to help users in icon grouping. Consequently, the design of the alternative interface is different to the folder interface of the original study. The alternative interface Bin is mainly based on an existing concept, which is especially designed for digital tabletops.

In the following, Section 5.1-5.5 cover the design of the study (apparatus, task, method, design). Section 5.6 introduces the study procedure, Section 5.7 describes some characteristics of both interfaces and Section 5.8 gives information about the study group. In Section 5.9 the quality of the results is exposed. Section 5.10 presents and describes four groups of results: User Performance, User Preferences, Interaction Types and Gestures.

5.1 Grouping simple objects

The main goal of the study was to examine, if the bubble metaphor helps in spatial layouting tasks on digital tabletops. Therefore, participants were asked to group 30 simple colored squares on a digital tabletop according to their color.

Structuring visual artifacts can support the formal organization of shared surfaces (see Chapter 2). This study gains a first insight how the interaction concept of Blub works in the grouping task on digital surfaces and provides an outlook, if Blub can assist in structuring a designer's environment.

Reserch Questions

In order to undertake the user study, several research questions were formulated before:

- Do the participants understand Blub? If no, which aspects were not understood?
- Do participants complete significantly faster in one of both conditions? If yes, in which one?
- Which interaction concept is preferred by the participants? What are the reasons for their preferences?
- Which differences exist in the interaction strategies between the interfaces?
- Is there an interdependence between the task completion time and different operations?

Hypotheses

These research questions led to the following hypotheses:

- H1: The bubble metaphor works as Blub on digital tabletops.
- H2: Bin speeds up the grouping task.
- H3: The user will prefer Blub.
- H4: There are differences between the interaction strategies by using the Blub and the Bin interface.

The study results and the discussion give information about the use of the usability of the Blub and the Bin interface. For example, why participants preferred one interface more or were faster in the grouping task by using one specific interface. In the end, these results will help to answer the research questions and prove the formulated hypotheses.

5.2 Apparatus

The study was conducted on a Microsoft Surface prototype, measuring 24"' x 18"' set at 1024 x 768 resolution. The program was implemented using C# and the ZOIL Framework[1].

A digital tabletop was necessary for a proof of concept. The Microsoft Surface had an appropriate size for the task, as there was enough space to draw 30 small colored shapes and non-overlapping bubbles around those shapes in the Blub condition. One further reason for preferring the Microsoft Surface 1.0 over lab prototypes was the robustness of the system. In opposite to the prototypes, this table is a consumer product and works more reliable. For further studies, also other systems should be taken into account. The suitable size of a digital tabletop can depend on the number of users, the amount of artifacts and their size.

[1]http://zoil.codeplex.com

Aside from that, the content of the artifacts should be regarded as for example, detailed sketches with descriptions needed a higher resolution than simple colored shapes.

ZOIL (Zoomable Object-Oriented Information Landscape) is a design paradigm and a software framework, written in C# for the .NET/WPF platform. ZOIL is developed by the Human-Computer-Interaction Group of the University of Konstanz[2]. As ZOIL is a ZUI, an infinite information landscape can be used to show content. Thereby, visual zooming allows to focus on a region of interest. The reason for using ZOIL was the reusability as the main advantages of ZOIL can support future studies, which may consider new aspects. For example, ZOIL already provides a *semantic zooming* functionality, which can be used for hierarchical clustering (compare Dynapad [7] BrainDump [10]). The *distributed and real-time synchronisation* across multiple displays allows to evaluate collaborative settings with multiple displays (compare AffinityTable [18]). Besides, the *persistency* of ZOIL permits to conduct long-term evaluation, e.g. a field study in a design studio.

5.3 Task

Based on the work of Watanabe et al. [61], the task was to group 30 spatially distributed 2D shapes according to colors. The task was separated in two phases: grouping and regrouping.[3] First, the 2D shapes, colored in yellow, green, blue, pink and violet, were randomly distributed on the surface. None of the shapes was superimposed by any other. As soon as the shapes were loaded, participants were prompted to create one group for each color. The regrouping phase started after participants had finished the grouping. For this purpose, shapes changed their colors randomly. The number of shapes of each color as well as the position of each shape remained unchanged. Participants were asked to create one group of six shapes per color. If all 2D shapes were grouped according their colors, this phase was completed successfully. Otherwise, if participants needed more than five minutes for completing one phase and the current phase counted as unsuccessful, the next phase started automatically.

In short, the procedure of one task looked like the following (see also Figure 5.1):

1. Random distribution of colored digital 2D shapes.
2. Grouping of shapes according their colors by the user.
3. Shuffling colors of shapes.
   (Number of same colored shapes and position of shapes stay the same.)
4. Regrouping of shapes according to their colors by the user.

The whole task procedure consisted of 16 trials (4 passes x 2 interfaces x 2 phases). Whereby, only 12 trials (3 passes x 2 interfaces x 2 phases) were considered in data evaluation, as the first pass in each interface was only for tutorial and practice.

[2] http://hci.uni-konstanz.de

[3] The number of shapes was taken over from the original study and is appropriate for a first proof-of-concept. In a designer's environment, the number of artifacts depends on the size of the shared space, the number of projects and the number of designers, who use this shared space. In a live session (e.g. Affinity Diagramming [18]), 100 will be an adequate size.

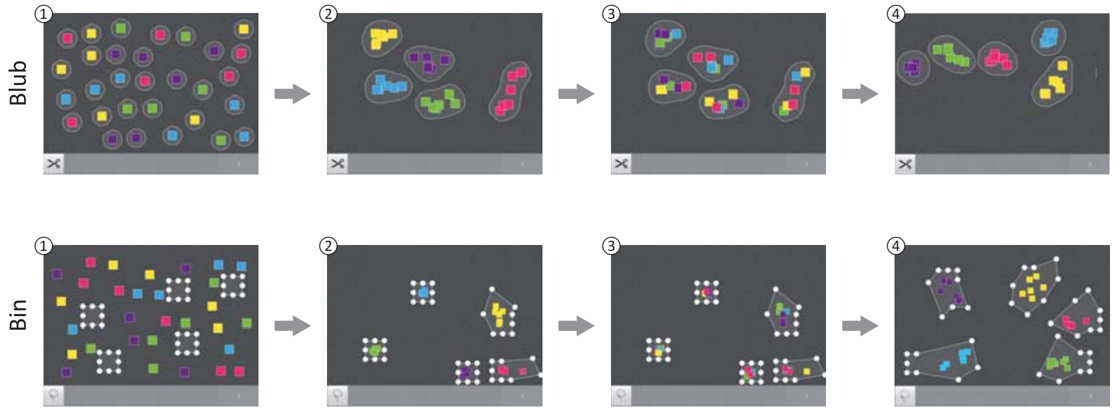


Figure 5.1: (1) Positioning objects randomly. (2) Result of grouping. (3) Shuffling colors of objects. (4) Result of regrouping.

5.4 Method

A controlled experiment was conducted to protect the object of investigation as far as possible against environmental influences in order to get better knowledge about both interfaces. To verify the hypotheses and answer the research questions, two questionnaires, a structured interview, video-recordings and logging data were gathered for later data analysis.

5.4.1 AttrakDiff™ and SUS

AttrakDiff™ [24] helped to distinguish between pragmatic and hedonic quality and showed the strengths and weaknesses of both interfaces. The results allowed to gain more insight into the perceived quality of the interface, the subjective interface preferences of the users and the general attractiveness of both interfaces and are especially interesting for future improvements of both interfaces.

The SUS (System Usability Scale) [11] was used to measure the usability of both interfaces in order to find out, if Blub works on digital tabletops in the grouping task. The principal investigator was able to ask, why a participant chose an uncommon rating[4], as the SUS was designed as directed questionnaire.

5.4.2 Data Logging

The essential quantitative data source for identifying different interaction strategies were data logs. Therefore, each occurrence of an interaction technique was logged together with a timestamp, the user's ID, the interface type, the current task, the current task status and further comments in a *.csv file. The large amount of attributes was used for filtering the data sets during data evaluation. Start and end time of each phase were logged together

[4] *Uncommon* means here, that it was different to the average rating of the study group.

with the current task status for measuring the task completion time. Figure 5.2 shows a short sample of the logging data.

Timestamp	UserID	Interface	Task	Status	Operation	Comment 1	Comment 2
08:40:35	1	BLUB	GROUPING	STARTED	TASK	STARTED	
08:40:45	1	BLUB	GROUPING	STARTED	GROUP		OBJECT
08:41:49	1	BLUB	GROUPING	STARTED	SPLIT		
...	...	...	...	...	...	...	...

Figure 5.2: Sample data log of the beginning of one phase.

5.4.3 Video Recording

The video recordings were used for qualitative analysis, since they can enhance quantitative data logs. For example, interaction strategies can not always be clearly extracted from quantitative data. It is also difficult to reflect upon gestures, bi-manuality or the use of multiple fingers for interaction without any video recordings. Therefore, the qualitative data was necessary to answer some of the research questions.

5.4.4 Interview

In the end of the study procedure, participants were familiar with both systems. As the whole procedure took at this point already approximately 50 minutes and included four questionnaires (2x SUS, 2x AttrakDiff™), the comparative rating of both interfaces was ascertained by interviewing the participant. This allowed the principal investigator to examine the reasons for their preferences concerning one interface in more detail. The principal investigator was able to react spontaneously to interesting statements. An interview manual (see Appendix A) was prepared[5] in order to keep the interviews across participants consistent.

5.5 Design

Each of the participants met the Blub and the Bin condition. A balanced within-subjects design was chosen in order to avoid learning effects. Six participants started with the Blub and the other six with the Bin condition. Like in the original study [61], one duration of one session was approximately 20 minutes. The whole procedure took around 60 minutes.

5.6 Procedure

In the beginning, participants were asked to fill out a questionnaire concerning their demographic data and their experience with computers and touch devices. Then, they got

[5] As a guideline Heistinger's guide of preparation and execution of interviews [25] was taken into account. The method used is based on the work of Helfferich [26].

a written introduction to the procedure and to the task. They received the first interface introduction, which illustrated the interaction techniques of the interface. These involved the code of practice and the purpose of each interaction technique. In the next step, the participant was asked to sit down at the digital tabletop. The principal investigator showed the participant special characteristics of each interface (see Section 5.7), after which the participant was asked to try out all of these interaction techniques described in the interface introduction. This was already one pass of the task, but was not taken into account as the purpose was tutorial and practice. Data recording started after this first pass and participants completed the task three more times. Between the grouping and regrouping phase, participants had a short break of five seconds. After each pass, there was a long break of one minute for relaxation. Participants were requested to stand up and fill out the AttrakDiff™ questionnaire after they had finished all four passes. The principal investigator asked participants for their ratings in the SUS. After completing the first session, participants got the written introduction to the second interface and the procedure started again. Participants were interviewed by the principal investigator after both sessions. Finally, participants received their payment and were seen off. All documents handed out to the participant can be found in Appendix A.

5.7 Interfaces

Sections 4.1 and 4.2 describe the Design Rationale for both interfaces in detail. In the user study, participants were introduced to the functionality of both interfaces and were asked to try out all gestures in the tutorial. Before participants started with the interaction, the principal investigator announced some special characteristics of each interfaces.

Participants were informed about the physical behavior of the digital objects on the surface. For example, an object can be tossed across the surface by simply poking an object with the finger. Furthermore, the principal investigator showed the usage of multiple fingers for object manipulation on the digital tabletop. Some objects were dragged with multiple fingers across the surface therefore. For the Blub condition, a problem in the visualization of a bubble was brought to the participant's attention. The major problem was that objects belonged to a bubble but were not surrounded by it. For this reason, the principal investigator presented one way to solve the problem. Therefore the cutter was applied on the edge of the transparent bubble shape between the obviously bubble-related objects and those which were connected to the bubble but were not inside the boundary. The result was that the bubble was split into two new bubbles and participants knew how to handle this problem.

5.8 Participants

15 participants were recruited for the study mainly from the local university. Color blindness was a knock-out criteria for candidates as the task was to group colored shapes. Two of the participants took part for the Pre-Test, but were excluded from data collection. Another dataset was not considered in data evaluation due to large difficulties in dealing with touch as input media. Ultimately, twelve participants (seven male and five female,

aged 21 to 39, mean: 26) passed the study successfully (see Section 5.9). Half of them were undergraduates, the other half held already an university degree. Ten of the participants were students, one was a research assistant and another one worked as a consultant. Except two, all of them had no background in computer science. Three of the participants were left-handed and the rest was right-handed. Concerning the time per day, they spend in front of the computer, half of the participants stated they spend more than three hours a day, the other half was just below. With regard to their experience with touch as input device, only one had never used a touch device before. All others were familiar with ticket machines (11 / 12), smartphones (10 / 12) or tablets (8 / 12). On a 5-point Likkert scale (*5 = much better, 1 = much worse*), participants rated touch input on average (3, 91) better than other input devices. For the participation, all participants were rewarded 10 Euros for their efforts.

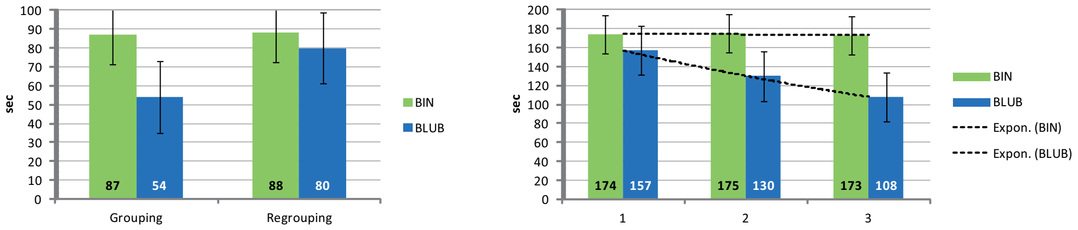
5.9 Quality of Results

Twelve data sets consisting of two questionnaires, data logging and video recordings of two sessions (Blub and Bin interface) and a final interview were used for data evaluation. Some single trials were ignored due to too high task completion times as trials were canceled by the system after five minutes. Finally, 68 trials for Blub and 71 trials for Bin were used for data analysis.

User performance was measured with the task completion time (see Section 5.10.1). As some interaction strategies were not considered by the interface designers, some trials suffered from high computational effort (e.g. bubble visualization), which lead to bad user performances. This problems will be discussed in more detail in Section 6.2.

Section 5.10.2 describes the results of the two questionnaires. At this point, it should be mentioned that the SUS was applied in a different manner as usual. Brooke [11] suggested to use the SUS directly after a user's performance. There should be no discussion in between the use of the system and the questionnaire. As this study's aim was also to figure out, why participants had troubles with an interface or would like to use it again or not, the idea was to design the SUS as directed questionnaire. The main advantage was that the principal investigator had the possibility to enquire about unexpected answers. Moreover, it was decided to give the AttrakDiff™ first as to avoid any influences in the results through discussions of the directed SUS questionnaire. Additionally, Hassenzahl et al. [24] recommended to use the AttrakDiff™ for more than 20 participants. In spite of the fact that this study involved only twelve participants, the results may not be representative, but give an impression of how far results between both interfaces can differ in the pragmatic and hedonic quality or in attractiveness.

Different interaction types were presented for both systems in Section 5.10.3. The idea behind logging the operations (see Section 5.4.2) of the corresponding interface was to investigate the variety of interaction strategies. During data evaluation, it was clear that this data is only the start point for covering different interaction strategies, as there is an amount of other variables which have influence and can not be seen in the quantitative data. However, the logged data is the starting point for a more qualitative analysis.



(a) (b)

Figure 5.3: (a) Average trial time and standard deviation of phases in both conditions. (b) Average trial time, standard deviation and exponential tendency across passes.

At this point, it should be mentioned that the investigation of gestures was not the main issue of this study. Gestures were prospected regarding bi-manuality and the number of fingers included in interaction in Section 5.10.4. Data was only analyzed in a rough manner. If future researchers want to know the exact amount of operations in which both hands or multiple fingers were integrated, video recordings have to be studied in more detail. The reason for this superficial analysis was to get an idea of whether there are any differences between both interfaces or not concerning bi-manuality and the usage of multiple fingers.

5.10 Results

The next sections describe the results of the user study. In order to answer the different research questions and provide some structure, results were divided into four topics. User performances were measured by the logged task completion times (see Section 5.10.1). Two questionnaires provide information about user preferences in Section 5.10.2. Some primary findings concerning interaction types were shown in Section 5.10.3. Section 5.10.4 raises the issue of gestures in the sense of bi-manuality and multiple finger input.

5.10.1 User Performance

The start and end time of each trial were logged in order to measure the user performance. Average trial time and standard deviation are shown for grouping and regrouping phase in Figure 5.3a. According to that, there is a tendency that participants were faster in interacting with Blub than with Bin, but paired T-tests point out, that there is no significant difference in the average trial time ($t(12) = 0.29579, p < 0.001$)[6]. However, considering the grouping and regrouping phase alone, depicts that especially the grouping phase was solved faster by using the Blub interface. Paired T-tests for the grouping phase show significant differences between Blub and Bin interface ($t(12) = 0.00063, p < 0.001$). There are also differences in the regrouping phase, which are not significant ($t(12) = 0.03708, p < 0.001$).

Some results of the task completion times of each participant can be seen in Figure 5.4. All participants expect two ($T6$, $T15$) were faster in the Blub condition. By far the largest

[6] $t(12)$...T-Test: Blub and Bin.

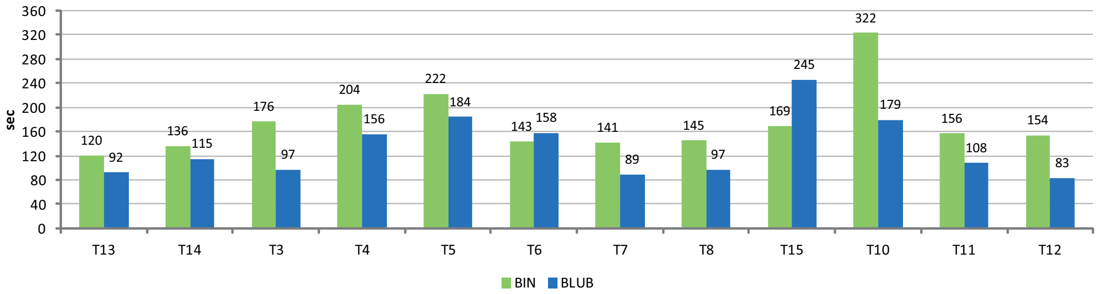


Figure 5.4: Average trial times by participants per condition.

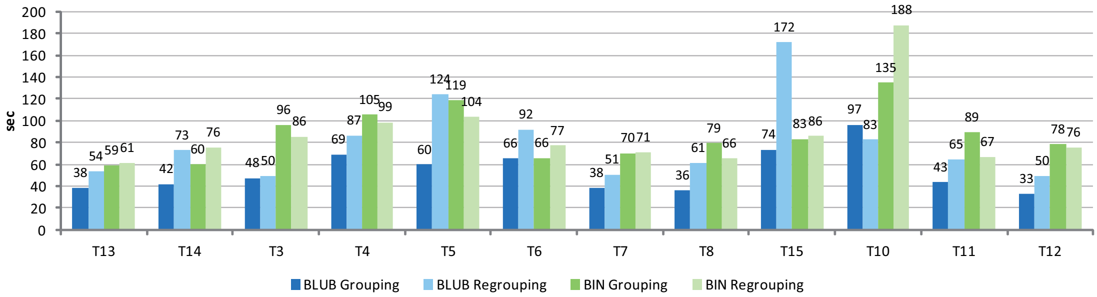


Figure 5.5: Average trial times for grouping and regrouping phases by participants for both interfaces.

differences in the task completion time is found in the performance of $T10$. $T13$ and $T14$, who acted nearly equal fast with both interfaces, have the slightest fluctuations.

By breaking down the data of each participant to the level of phases (see Figure 5.5) some more results can be found[7]. Comparing both phases of both conditions, the fastest performances are found in the grouping phase of the Blub condition ($T12 \in A_g = 33s$, $T8 \in A_g = 36s$, $\{T7, T8\} \in A_g = 38s$). Contrarily, the slowest passes are shown either in the regrouping phase of Bin ($T10 \in B_r = 188s$) and Blub ($T15 \in A_r = 172s$) or the grouping phase of Bin ($T10 \in B_g = 135s$). On average, Blub's grouping phase was completed by far more quick ($\bar{T} \in A_g = 54s$) in opposite to all other phases. All of them took around 85 seconds ($\bar{T} \in A_r = 80s$, $\bar{T} \in B_g = 87s$, $\bar{T} \in B_r = 88s$). In general, performances in the grouping phase of Blub were faster than in all other phases.

Figure 5.6 and Figure 5.7 consider all passes[8] of one participant. At this point, it is important to note that the incomplete data sets of $T4$ and $T10$ in the Blub and $T3$ in the Bin condition are due to canceled tasks (see Section 5.3). In the Blub condition, six of twelve participants ($T13$, $T14$, $T5$, $T7$, $T15$, $T10$) had a tendency to became faster, none of the participants finished slower across the three passes (see Figure 5.6). According to Figure 5.7, only $T5$ completed faster and even three of them ($T13$, $T14$, $T10$) became

[7]In the following, task completion times were described as mathematical quantities: Blub Grouping A_g, Blub Regrouping A_r, Bin Grouping B_g, Bin Regrouping B_r.
[8]One pass consisted of a grouping and a regrouping phase.

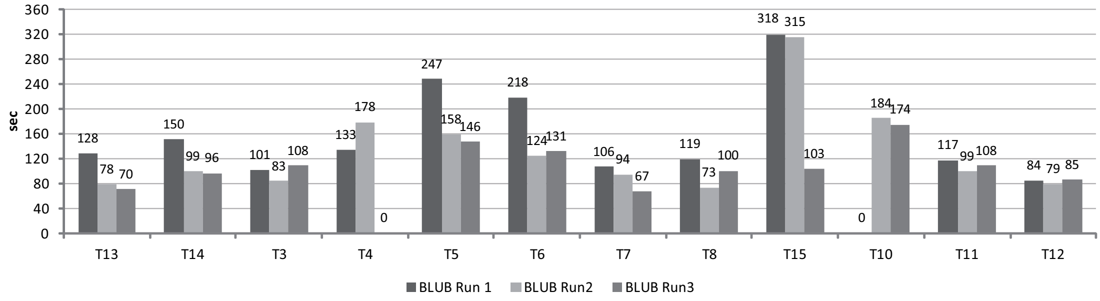


Figure 5.6: Trial times of the three passes by using the Blub interface.

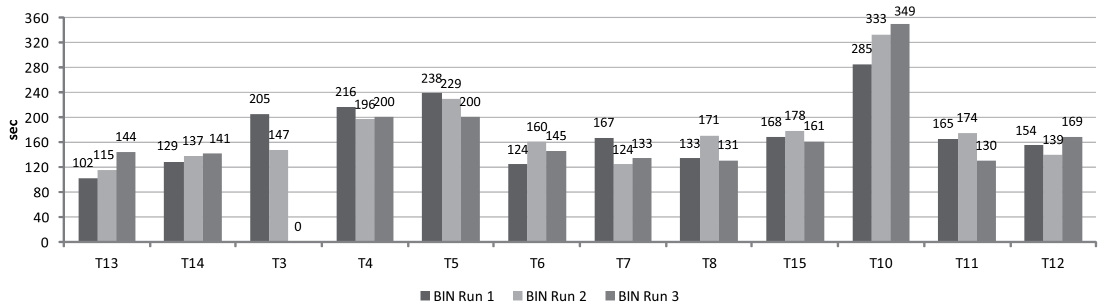


Figure 5.7: Trial times of the three passes by using the Bin interface.

slower. In most cases the task completion time only changed a little during the three passes for the Bin condition.

To sum it up, Figure5.3b shows a tendency that participants became faster across the passes by using the Blub interface. The difference between first and third pass was 49 seconds on average. In contrast to that, the ordinary user performance remained almost the same during the three passes in the Bin condition.

5.10.2 User Preferences

Participants received two standardized questionnaires (see Section 5.4.1) after the usage of each interface in order to receive an impression of the preferences of the users. In the end of the procedure, participants were asked for their preferred interface (see Section 5.4.4). The following sections describe the quantitative results of both questionnaires. The results of the interviews are covered in the discussion in Chapter 6.

SUS

The SUS (System Usability Scale) allows users to rate the overall subjective impression of usability. Therefore, users were asked to evaluate ten statements on a five-point Likkert-scale from *1 = I fully agree* to *5 = I completely disagree.*

According to the received user ratings of the twelve participants, both interfaces were perceived very positively. Participants rated the usability of Blub with an average SUS score of 91%. This result differs significantly opposing to the Bin interface ($t(12) = 0.02745, p < 0.05$). According to the adjective rating scale of Bangor et al. [5], the Blub interface can be described as *Best imaginable*. In correspondence with this, the Bin interface with a value of 81% can be designated as *Good* or *Excellent*.

Results of the SUS show, that some statements spread opinions more than others. In rating the Blub interface, participants had not reached an agreement concerning the statement *"'I would imagine that most people would learn to use this system very quickly."'* ($SD_7(12) = 0.651$)[9]. Regarding the Bin interface, participants were divided about the statement *"'I found the various functions in this system were well integrated."'* ($SD_5(12) = 1.115$) and *"'I found the system cumbersome to use."'* ($SD_8(12) = 1.030$). In the statement *"'I think that I would like to use this system frequently."'* opinions were in both interfaces distributed (Blub: $SD_1(12) = 0.965$, Bin: $SD_1(12) = 1.084$). In general, participants agreed more in rating the Blub than in the Bin interface. Comparing the ratings for both interfaces shows that participants would significantly ($t_1(12) = 0.02971$) more frequently use Blub ($\bar{s_1}(12) = 4.25$) than Bin ($\bar{s_1}(12) = 3.42$)[10]. Furthermore they rated Blub ($\bar{s_8}(12) = 1.42$) significantly ($t(12) = 0.01911$) less cumbersome to use than Bin ($\bar{s_8}(12) = 1.67$).

AttrakDiff™

The AttrakDiff™ is a standardized questionnaire, which allows users to rate a product within a scale of two opposing adjectives (e.g. complex - simple). The 20 word pairs concern the *pragmatic quality (PQ)*, *hedonic quality - stimulation (HQ-S)*, *hedonic quality - identity (HQ-I)* and *attractiveness (ATT)*[11]. Pragmatic and hedonic quality result to equal parts in the attractiveness.

Figure 5.8 illustrates that the PQ of Blub was rated very high, which means that it is more *task-oriented* than *self-oriented*. Concerning the HQ, the confidence rectangle of Blub crosses the intermediate field *task-oriented* as well as the more identity-related field *desired*. According to this, the Blub interface allows the user to identify himself with the interface and the interface is not only practicable. In contrast to that, the Bin interface is a little more rated as *task-oriented*. In the PQ dimension, the Bin interface is little more rated as *neutral*, which means that this interface could be improved concerning the support it gives to the user for completing a specific task. Nevertheless, participants were more in agreement regarding the Blub interface. Opinions differ more in rating the Bin interface, which is shown by the confidence rectangles. Generally, Blub was in all four categories rated better than Bin.

[9] $SD_n(12)$...standard deviation across all participants for the n^{th} statement of the SUS.

[10] $\bar{s_n}$...describes the average rating of the n^{th} statement.

[11] *Pragmatic quality* is the usability of the product and how good users successfully reach their aims by support of the product. *Hedonic quality - stimulation* describes to what extent the product supports a user's progress by providing new, interesting, inspiring functionalities, contents, interaction- and presentation styles. *Hedonic quality - identity* indicates a value for the amount a user is able to identify himself with the product. *Attractiveness* is a general rating of the product on basis of the perceived quality. More details can be found in Hassenzahl et al.'s work [24].

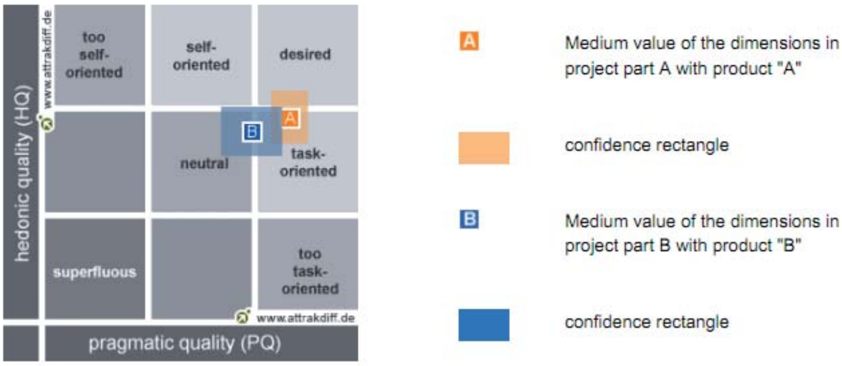


Figure 5.8: Medium values of the dimensions and confidence rectangles for both conditions (Blub: *A*, Bin: *B*).

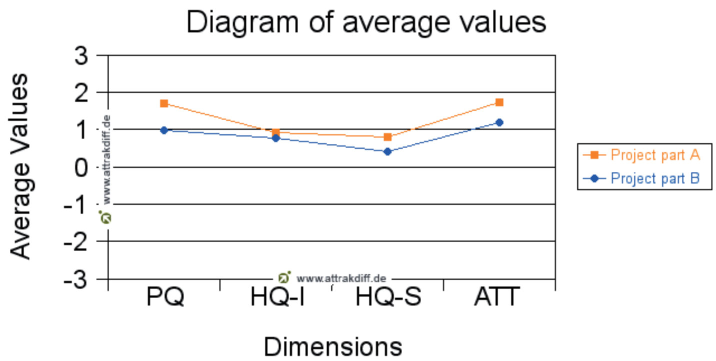


Figure 5.9: Mean values for *pragmatic quality*, *hedonic quality - stimulation*, *hedonic quality - identity* and *attractiveness* for both conditions (Blub: *A*, Bin: *B*).

Figure 5.9 shows all four dimensions and the mean values of the Blub and the Bin interface. This diagram illustrates that the interfaces have small differences in the PQ, HQ-S and the ATT. The HQ-I is almost the same. These results are based on large differences in single word pairs of the corresponding category. For example, the dimension of PQ of Blub is better judged by participants, because they rated Blub as more *practical*, *clearly structured* and *manageable*. Both interfaces were assessed positively concerning PQ and were perceived as more *technical* than *human*. Regarding both HQ dimensions, the average rating was again very good for both interfaces. Differences in-between might arise from participants characterizing Blub as more *inventive* and *challenging* than Bin. The dimension of ATT presents that Bin was perceived as less *pleasant* than Blub. Beyond that, participants rated the Blub interface more *attractive*, *likable* and *inviting*, but less *motivating* than Bin.

5.10.3 Interaction Types

Data about the used operations was logged in consideration of requesting information about different profiles of interaction (see Section 5.4.2). One reason for doing this, was to see whether special interaction profiles correlate with slow or fast user performance. Another

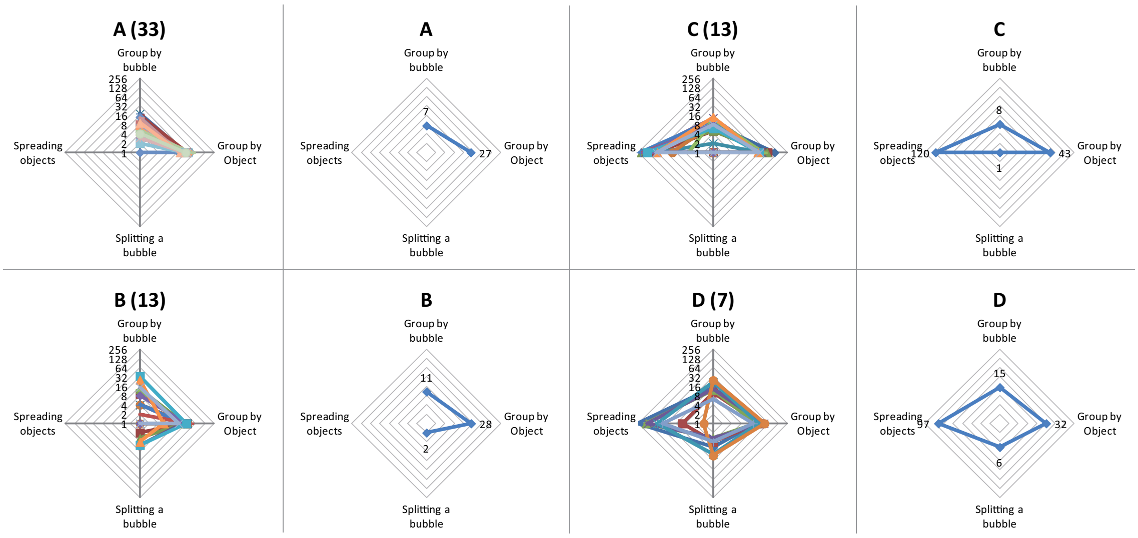


Figure 5.10: Interaction Types for Blub.

reason was to find out if there is a any connection between bi-manuality, interaction with multiple fingers (see Section 5.10.4) and specific interaction profiles. In total, 139 interaction profiles (spider diagrams) were prepared for data analysis. From 144 spider diagrams (2 interfaces x 12 participants x 3 passes x 2 phases), five diagrams of the Blub and one diagram of the Bin condition were excluded due to uncompleted phases. As a consequence of a high variety in the number of operations, the reference axis was scaled logarithmically to the base of two. The axis ranges from 1 to 256 and the main interval is 2.

The following sections introduce the variety of interaction types for both interfaces. After, a short introduction into the used terminology, a summary across the number of interaction types is given. Afterwards, interaction profiles with the aggregated data as well as an average profile and a description of each interaction profile are shown.

Blub

According to the Design Rationale (see Section 4.1), four different operations were logged in the Blub condition. *Grouping by bubble* is the merging of two bubbles by dragging and releasing the bubble itself. *Grouping by object* means the grouping of one single object in a bubble to another bubble by moving that object. *Splitting a bubble* is the description for splitting a bubble into two. *Spreading objects* specifies the expansion of overlapping objects in one bubble.

In total, 68 data sets provided the information for creating four different interaction types. Figure 5.10 shows these types. On the left side, the aggregated data for one type is shown. The right side presents the average interaction type. In total, type *A* was found in 33, *B* and *C* both in 13 and *D* in 7 data sets. On average, users interacting like *A* grouped seven bubbles by dragging a bubble and melt bubbles together in 27 cases. Type *B* users applied thereby in mean two splitting operations to complete one phase (grouping or regrouping). 13 data sets were associated with type *C*. For this profile, users executed

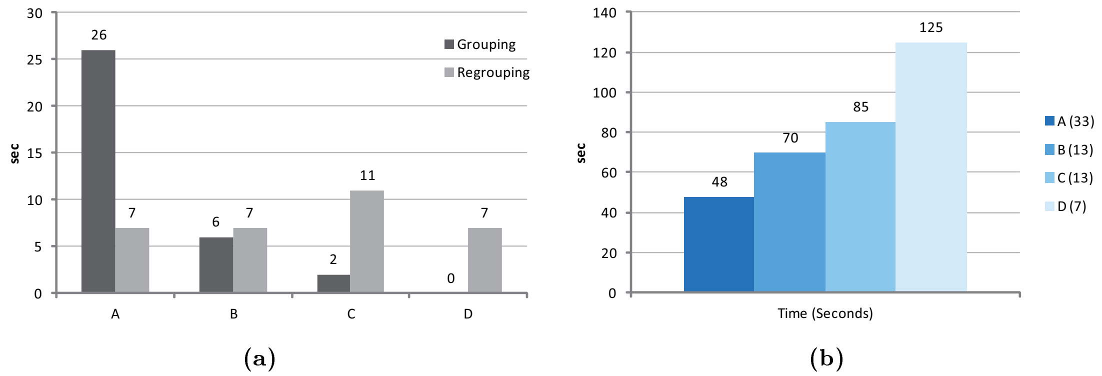


Figure 5.11: Blub: (a) Number of profiles of each type per phase. (b) Average completion time for each type in seconds.

the spreading operation in order to get an overview on average 120 times per phase. Profile D is the most complex interaction type. Melting bubbles together was used around 15 times, grouping an object to a bubble was executed about 32 times. Moreover, users split a bubble six times and spread objects on average 97 times. In general, the number of profiles related to one type correlates with the amount of different operations used in the phase.

On examination of the number of occurrences of one type, differences between grouping and regrouping phases can be found. Figure 5.11b indicates that type A was especially used in the grouping phase and was the most popular one. For the regrouping phase especially type C was popular. All four operations (type D) were also only used in the regrouping phase. In general, all interaction types were equally distributed in the regrouping phase.

To get some more information about the success of each interaction type concerning user performance, the types were opposed to the task completion times (see Section 5.10.1). Figure 5.11b shows a bar chart with the mean time for each interaction type. Participants interacting like A needed on average 48 seconds. Applying type B took around 70 and the mean completion time of C was 85 seconds. The most complex interaction type D completed one trial in about 125 seconds.

Bin

For the creation of the interaction profiles, in accordance with the Design Rationale (see Section 4.2), five distinct operations were taken into account. *Collecting objects* is the collection of objects through dragging and releasing a bin. *Dragging objects into a bin* is the reverse operation, as objects can be moved separately into a bin. *Selecting and moving objects* is the process of making a free-form selection of objects and moving the selected objects to their destination. *Adjusting a bin* means to move a handle of a bin in order to resize or change the bin's shape. *Spreading objects* depicts the expansion of superimposed objects in a bin.

As Bin provides five operations, more complex interaction types were extracted from data. Seven different interaction types were found and four further profiles could not be

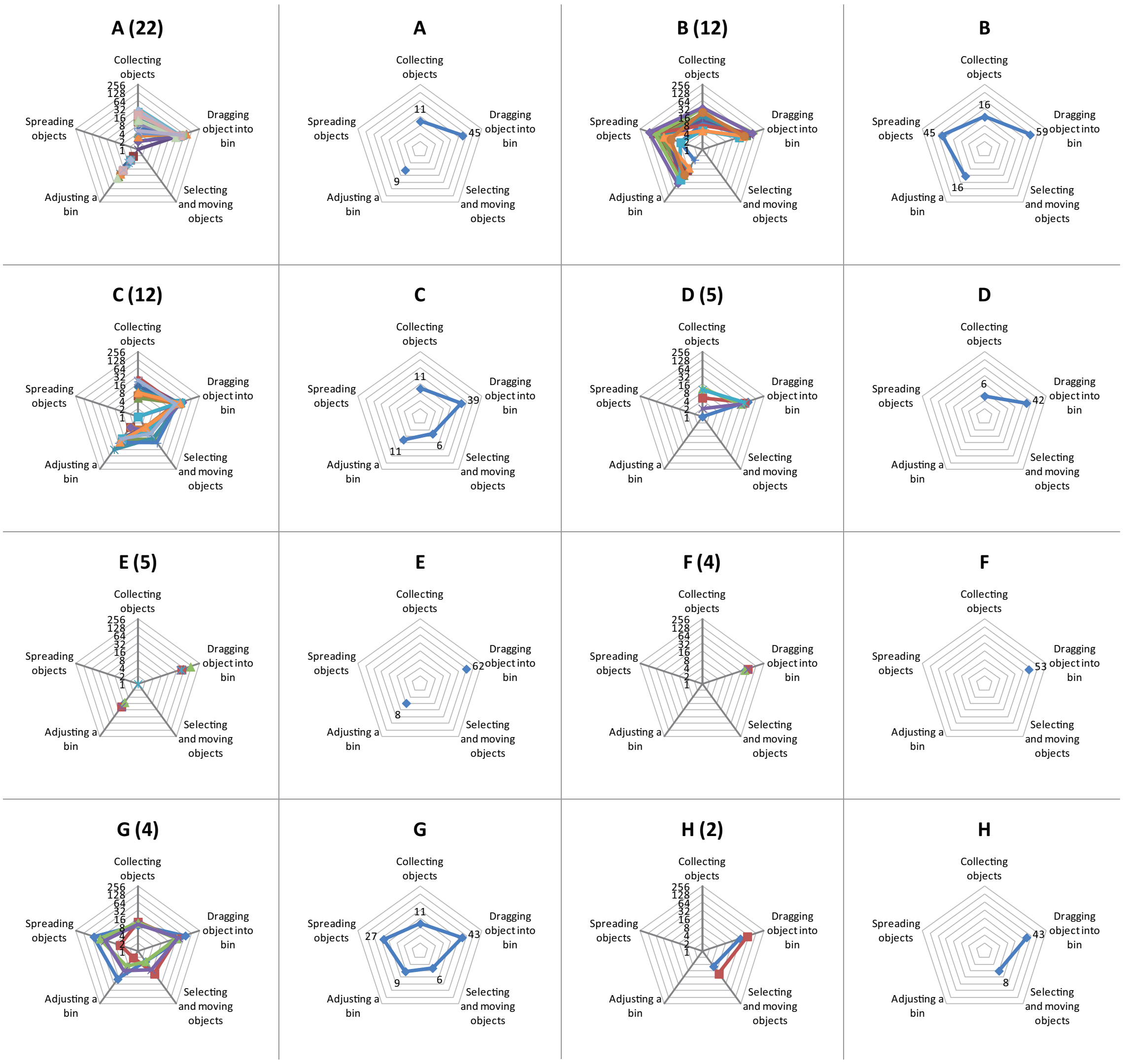


Figure 5.12: Interaction Types for Bin.

clearly assigned to one of these interaction types and are not be considered in the following. Type A was the most frequent used by far (22 times). On average, users collected objects eleven times, dragged objects into a bin 45 times and adjusted a bin nine times. Type B expands this profile by adding the spreading operation. Participants spread objects in a bin 45 times on average, collected objects 16 times, dragged objects into a bin 59 times and adjusted the bin 16 times. In contrast to that, type C is also based on type A, but permits to select and move objects by using a lasso tool. The number of collecting operations was the same as in A, but the dragging into bin operation is reduced to 39 times and selecting and moving objects was used six times. In addition, adjusting a bin was executed eleven times on average. Type D reduces type A through the adjusting operation. Collecting objects was executed six and participants dragged objects 42 times into bins. Contrary to that, type E dragged only objects into the bin (62 times) and adjusted the bin (8 times). The most simple interaction type was F. Dragging objects into the bin (53 times) was the

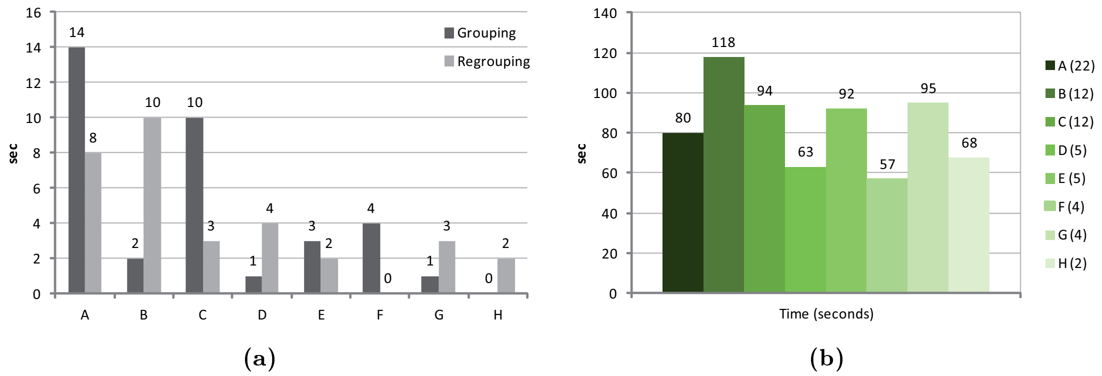


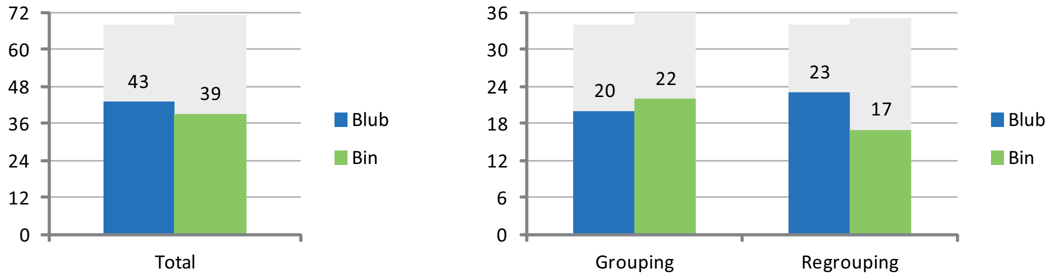
Figure 5.13: Bin: (a) Number of profiles of each type per phase. (b) Average completion time for each type in seconds.

only and the preferred operation for this type. G was the most complex interaction type, as all five operations were covered by this type. Selecting and moving objects was used six, adjusting a bin nine and collecting objects eleven times. The spreading gesture was executed 27 times on average. The most frequent operation for this type was dragging an object into a bin (43 times).

With respect to the different phases of the task, Figure 5.13a indicates that some interaction types were particularly used for one phase. For example, type A was the most frequent one in the grouping phase, followed by the type C. All other types were nearly equally distributed. In the regrouping phase, trials belonged to all types expect type F. Most profiles in this phase were classified as type B. All in all, in particular in the regrouping phase interaction types varied among trials.

Figure 5.13b presents the mean task completion times for one trial for each interaction type. In contrast to the interaction types of Blub, times do not correlate with the usage frequency of the profiles. An interesting fact is, that all types (expect E) with a maximum of three different operaftions (A, D, F, G) indicate the fastest time. Four profiles were aggregated to type F. Participants using this interaction type just dragged objects into a bin and completed one phase on average in 57 seconds. A combination of dragging objects into a bin and collecting objects (D) or drawing a lasso selection and moving objects (H) resulted also in a better user performance with around 65 seconds for one phase. C, E and G also had approximately the same task completion times. The one thing in common of all three types is that the distribution of dragging an object into a bin and adjusting a bin is pretty the same. Despite, E just used two interactions, C four and G all five. Interaction type B was by far the slowest one with an average time of 118 seconds per phase. B had the most spreading operations in contrast to all other types.

There is a wide variety of interaction types in the Bin condition. The number of executed operations ranged from one to five. Nevertheless, no clear connection between the number of operations of one specific interaction type and the task completion times can be found. The task completion time of the most frequently used type A is just in the midrange.



(a) (b)

Figure 5.14: (a) Number of two-handed interaction trials per interface. (b) Number of two-handed interaction trials in phases per interface.

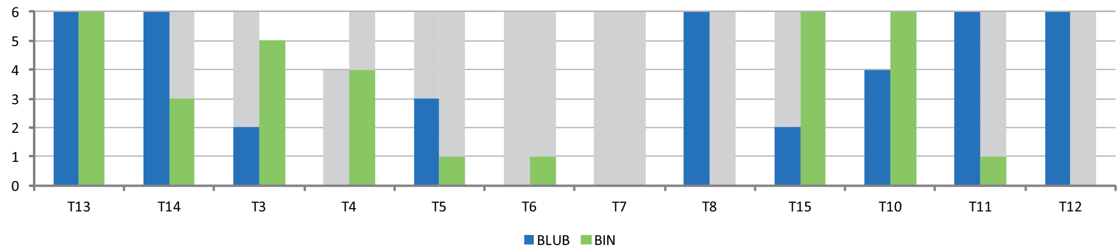


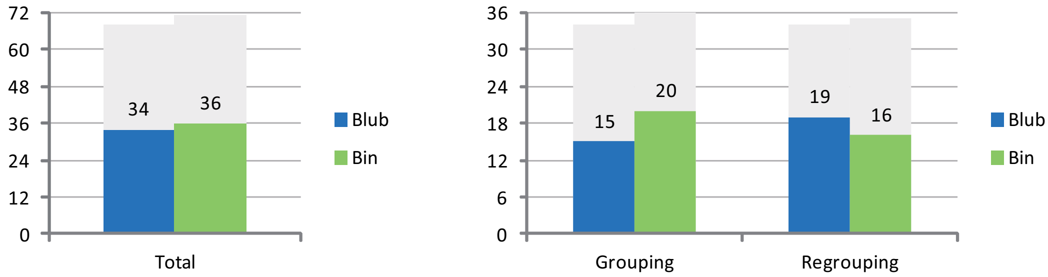
Figure 5.15: Two-handed interaction trials per participant.

5.10.4 Gestures

In contrast to mouse input, touch input enables users to interact with both hands and more than one finger. Therefore, data regarding these two factors was recorded. The primary focus was to investigate the main differences between the Blub and the Bin interface concerning the use of both hands and multiple fingers. So, videos were analyzed in respect of these factors and each trial of grouping and regrouping was coded in regard to any usage of both hands or multiple fingers. If at any point in time of the trial, both hands were used, the trial counted as two-handed. The same was also applied for the interaction with multiple fingers. It is important, that pushing the cutter-button for splitting in the Blub and pushing the lasso-button for selecting in the Bin condition were excluded and not counted as bi-manual interaction as they were handled almost with two hands. Spreading was also rejected as the design of this gesture implied already the use of multiple fingers.

Bi-Manuality

Bi-Manuality is still a topic in current research (compare North et al. [45]). In this study, the issue was to determine if one of the concepts is more appropriate for using both hands than the other. Figure 5.14a illustrates the number of trials in which participants used both hands for interaction at least one time. Blub covered in total 68 trials and Bin 71



(a) (b)

Figure 5.16: (a) Number of multiple finger interaction trials per interface. (b) Number of multiple finger interaction trials per interface split up in phases.

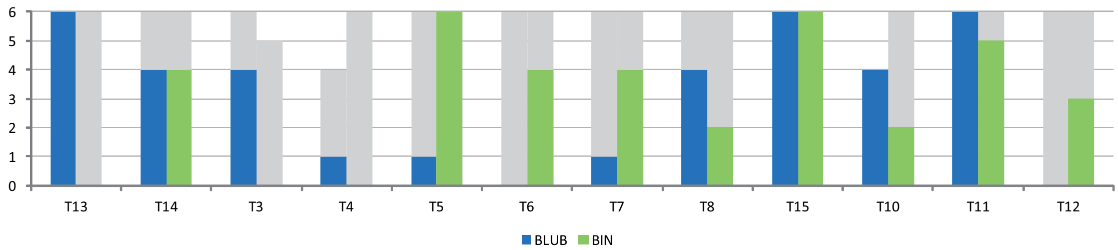


Figure 5.17: Number of multi-finger interaction trials per participant.

trails[12]. Participants practiced more often with both hands in the Blub interface (43 trials) than in the Bin condition (39 trials), even though this difference is not significant ($t(12) = 0.37426, p = 0.05$). Looking a little bit closer and separating the trials regarding the grouping and regrouping phase shows that both hands were in the Blub grouping and regrouping phase as often used as in Bin's grouping phase (see Figure 5.14b). Contrarily, more Bin regrouping trials were done with one hand than with both hands.

Figure 5.15 shows the preferences for each participant. $T13$ and $T10$ favored two-handed interaction in all of their trials. Half of the participants ($T13$, $T14$, $T8$, $T10$ $T11$, $T12$) liked using both hands in all trials of the Blub condition and four users ($T13$, $T3$, $T15$, $T10$) interacted with both hands in all trials of the Bin condition. Despite, some participants adopted single-handed interaction more (e.g. $T6$ and $T7$), who nearly never used both hands for interaction. Some participants (e.g. $T4$, $T8$, $T12$) found two-handed interaction appropriate for one interface, but not for the other, which is another interesting aspect.

Multiple Finger Input

Besides bi-manuality, videos were studied concerning multiple finger input. The goal was to investigate if users interact more with multiple fingers by using one of both interfaces. 68 completed trials of the Blub condition and 71 completed trials of the Bin condition were

[12]The number of possible trials is in the following always shown as a gray bar in the background.

analyzed therefore. As Figure 5.16(a) depicts, the number of trials, in which participants used multiple fingers was quite the same for the Blub (34 trials) and the Bin interface (36 trials). Paired T-test across participants show no significant difference ($t(12) = 0.42080, p = 0.05$). Figure 5.16(b) highlights that numbers for Blub's grouping (15 trials) and Bin's regrouping phase (16 trials) were almost the same. The same applies for Blub's grouping (19 trials) and Bin's regrouping phase (20 trials).

Figure 5.17 presents the number of multi-finger interaction trials for each participant. In the Blub condition $T13$, $T15$, $T10$ and $T11$ always acted with multiple fingers. Only $T5$ and $T15$ used more than one finger in each trial in the Bin condition. Single-finger interaction was preferred by $T6$ and $T12$ in the Blub and by $T13$, $T3$ and $T4$ in the Bin condition. Interesting is, that $T4$ hardly ever used multiple fingers in contrast to, for example $T15$, who used more than one finger in each trial across interfaces. Furthermore, some of the participants liked multi-finger interaction for one but not for the other condition (e.g. $T13$). On average, participants applied multi-finger interaction in around half of the trials of both interfaces.

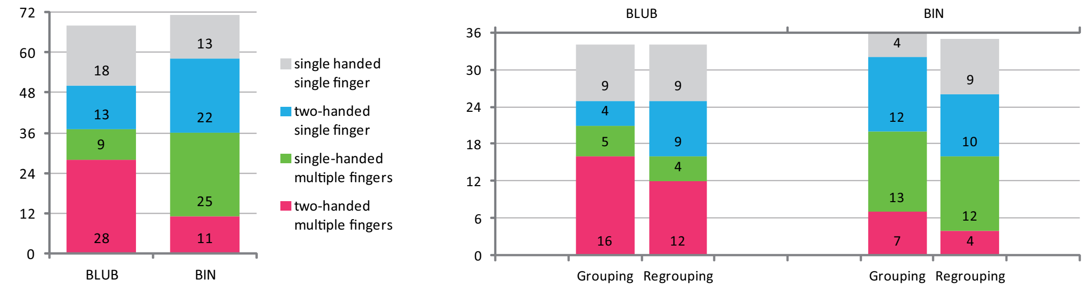
Interacting with both hands and multiple fingers

By using digital tabletops, the number of input channels raises with the usage of both hands and more than one finger. Bi-manuality and multiple finger input were examined separately in the last two sections. This section focuses on the crossing of bi-manuality and multiple finger input and aggregates the results of the last two sections.

Every combination of bi-manuality and multiple finger input results in four different categories: *two-handed - multiple fingers*, *single-handed - multiple fingers*, *two-handed - single finger* and *single-handed - single finger*[13]. Figure 5.18a presents all four categories as stacked piles for each interface. Looking at this figure allows to assume that especially two-handed interaction in combination with multiple fingers was often used in the Blub condition. Participants more often used either two hands and singles fingers (22 trials) or one hand and multiple fingers (25 trials), while operating with the Bin interface. Both hands in connection with more than one finger were not even used in half of the trials in the Blub condition. In the grouping and regrouping phase (see Figure 5.18b), the trials were distributed approximately equally. Another interesting aspect is that both hands were used alike in Blub's grouping and regrouping phase, but the number of single and multiple finger input differs, as multiple fingers were preferred for the grouping phase.

Figure 5.19 illustrates the different interaction patterns of the participant for each interface in one stacked pile. None of the twelve participants had one preferred manner of interacting across both interfaces. $T13$ just used one pattern for each interface, but both included two-handed interaction. $T7$ varied between single-handed interaction in combination with multiple-finger and a single-finger input across both conditions. $T15$ liked multiple finger input, but decided to use either one or two hands. Four of the participants ($T3$, $T6$, $T15$, $T12$) tried different combinations in the first interface, but applied just one

[13] At this point, it is important to note that single-handed means that both hands were never used in the corresponding trial. The same was applied for interaction with a single finger, which means that in the specified trial, the participant never used more than one finger.



(a) (b)

Figure 5.18: (a) Number of multiple finger interaction trials per interface. (b) Number of multiple finger interaction trials in phases per interface.

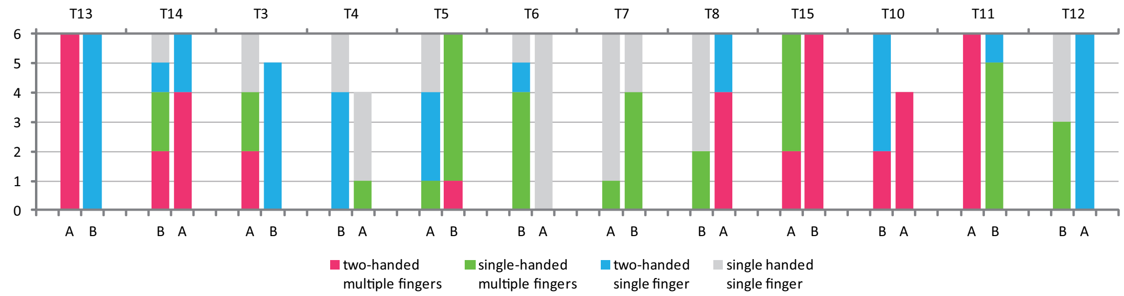


Figure 5.19: Each participants trials as stacked piles in ascending order of the used interface (Blub: A, Bin: B).

in the second interface. $T11$ chose the opposite way and changed from two-handed multiple finger interaction to two other combinations. In general, none of the participants tried only one combination, four varied between two, another four between three patterns and the remaining four applied the full spectrum.

5.11 Summary

In this chapter, the research goal, research questions as well as the hypotheses for the study were shown. The apparatus, the grouping task, the used methods, the study design and the procedure were described and information to the participants was given. The quality of the results was depicted and descriptive results were presented afterwards. These results concern *User Performance*, *User Preferences*, *Interaction Types* and *Gestures*. The following paragraphs summarize the main findings of the study. A detailed interpretation can be found in the next chapter.

Average task completion times were lower in the Blub condition than in the Bin condition. In consideration of all three passes, participants showed a learning curve by using the Blub interface. The difference between first and third pass was 49 seconds. Participants did not became faster by using the Bin interface.

139 interaction profiles were produced in order to evaluate the used operations of all trials. There were differences in the interaction strategies as both interfaces work differently. The 68 interaction profiles of the Blub interfaces were aggregated to four different interaction types. As a result, participants acting like type A had the best performances on average. This type was most frequently used (33 times) and primarily applied in the grouping phase. In regard to the user performances, the complexity of an interaction type correlates with a higher task completion time. Bin provides one operation more, which raises the complexity of the interface and consequently the variety of interaction types. 71 interaction profiles provided the base for the extraction of eight interaction profiles. All types, which applied a maximum of three different operations had the fastest task completion times. F was the simplest interaction type as users simply dragged objects into a bin. However, no clear connections between the number of operations and the average task completion times were found for the Bin interface.

In consideration of gestures, results have shown that each participant acted at least once with multiple fingers or both hands. Two-handed interaction in combination with multiple fingers was often used in the Blub condition in contrast to the Bin condition, where participants operated mostly either with the two fingers of both hands or multiple fingers of one hand.

Chapter 6

Discussion

The last chapter introduced the user study and showed the results of it. In order to get answers to the specified research questions and to verify the formulated hypotheses, this chapter discusses the descriptive results concerning *Adequateness and effectiveness*, *User Performance*, *User Preferences*, *Interaction Strategies* and *Gestures*. The following sections provide an interpretation with regard to these aspects and try to detect possible causes of the strengths and weaknesses of both interfaces.

6.1 Adequateness and effectiveness

Essential for the future use of the Blub interface or the interaction concept of Blub is to know if users understand the whole concept. One of the research goals was to figure out if participants understand Blub? The main hypothesis was that the bubble metaphor works as Blub on digital tabletops.

This hypothesis was confirmed as participants successfully completed the majority of trials with a success rate of 94%. The Bin interface had a higher success rate with 99%. The reasons for unsuccessful trials are depicted in the next sections.

6.2 User Performance

In Section 5.10.1, task completion times of both interfaces were shown. The general finding was that all expect two participants acted faster in the Blub interface. Participants became faster during the three passes of the Blub interface, but needed almost the same time for all three passes of the Bin interface. Task completion times were by far shorter for Blub's grouping phase than for Blub's regrouping phase and both Bin phases. A detailed breakdown of task completion times is shown in Figures 6.1- 6.4. Average task completion times are illustrated in the front and bars for each single trial are pictured as gray bars in the background.

There are many factors which influenced the performances of the users. The following sections cover these factors and examine possible explanations for the differences between task completion times of the users. One of the research goals of this study was to find out

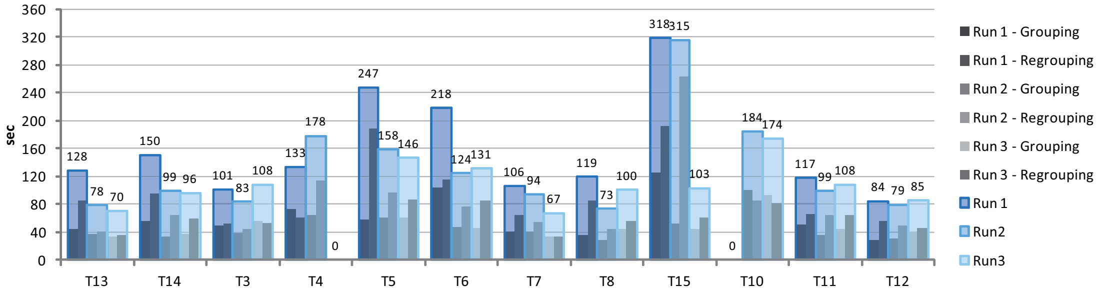


Figure 6.1: Blub: Average trial times across passes per participant.

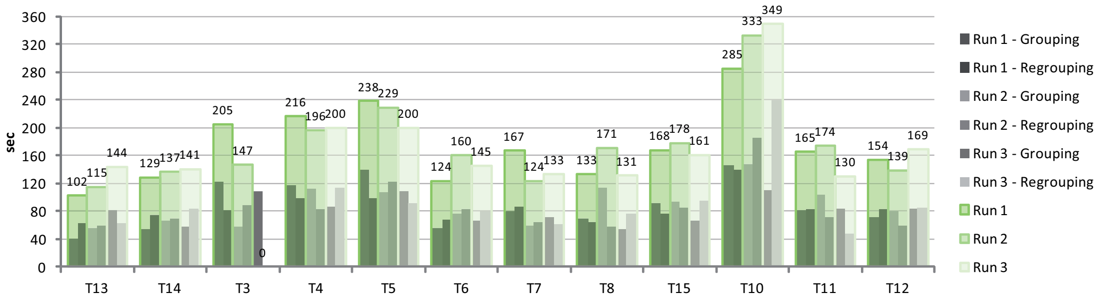


Figure 6.2: Bin: Average trial times across passes per participant.

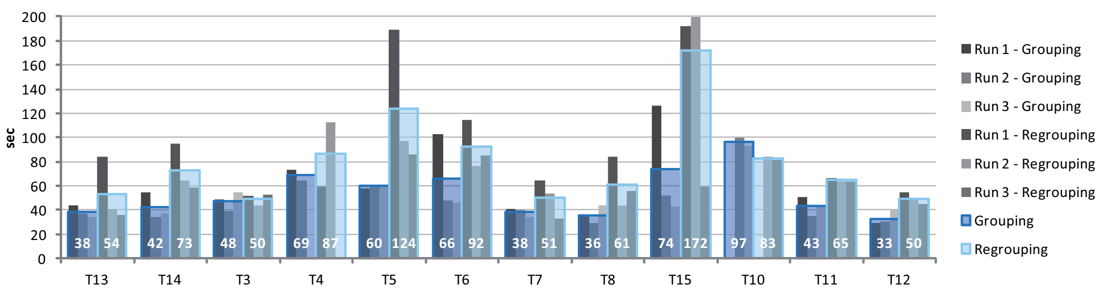


Figure 6.3: Blub: Average trial times for grouping and regrouping phase per participant.

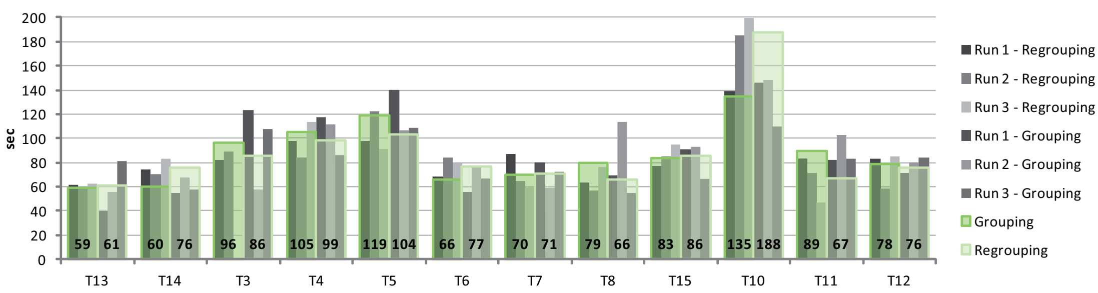


Figure 6.4: Bin: Average trial times for grouping and regrouping phase per participant.

if participants complete faster if they use either the Blub or the Bin interface. And if they do so, what are the reasons therefore? The main hypothesis was, that participants were faster in the grouping task by using the Bin interface. Therefore, aspects concerning the design rationale, performance issues of the system, the physical behavior of objects and effects of learning and fatigue are discussed in the following.

6.2.1 Interaction Design

During the trials, problems concerning specific interaction techniques were discovered. In future designs especially alternatives mode-switches for the cutter in the Blub and the lasso tool in the Bin interface should be taken into account.

The opinions of the participants were strongly polarized concerning the cutter in the Blub interface. Those who used the cutter very often ($T4$, $T6$) found it useful. In opposite to them, two participants ($T5$, $T7$) argued that the cutter is not expedient and slows down the grouping task. One problem was the activation of the cutter in the Blub condition. One participant ($T6$), for example, held the button too little and so the cutter was not activated. Another participant ($T8$), activated the button unintentionally with his left arm as the button was on the bottom left corner of the table. A further problem was, that interactions were only recognized, if they were initiated in the touch sensitive region of the table. As participants tried to cut outside this region, the interaction was disregarded by the system.

In the Bin condition the lasso tool was activated by pushing the button on the bottom left corner. In contrast to the cutter, participants only had to push the button once before they started with selecting objects. The major problem was that the lasso was activated until a selection had been moved. This lead to some unexpected troubles for the participants, as the mode switch disabled the handles for adjusting a bin. Some of the participants tried to adjust a bin, but just got a new lasso selection and get confused.

The lasso was rated better than the cutter by the participants. This is also evident with the data of the logging file. Only two used the cutter on regular base across the passes in the Blub condition. Comparing those, who split bubbles with those, who never used the tool, shows that the cutter slows down the grouping task. This had not to be directly related to the interaction technique itself. One possible explanation is also the usage of smooth animations while splitting, which takes some milliseconds. Contrarily, five of the participants selected objects with the lasso frequently. Concerning the lasso tool, no specific correlations to slower or faster user performances can be found. However, in both cases, pushing the button and activating a tool takes time and can lead to higher task completion times by using one of these interfaces.

6.2.2 Performance of the system

The calculation of bubbles with a large number of objects inside requires a high computational effort, which is the major problem of the Blub interface. For most of the participants, the performance of this algorithm was appropriate for the grouping task as they grouped not more than 15 objects. The problem just occurred, if participants created larger bubbles, for example if they merged all bubbles and tried to move an object inside the bubble's boundary. For example, in Blub's regrouping phase, $T15$ grouped all digital objects, executed a spreading gesture for getting an overview and sorted all objects inside the surrounding boundary. Each dragging operation forced the system to calculate the bubble contour again, which lead to a high computational effort, as the mathematical formula for the calculation raises with the number of objects belonging to a bubble and requires a very high computational effort. This obliged the participant to wait again and again until the bubble was visualized. So, the main reason for the bad performance of $T15$ (see Figure 6.3) was the unexpected interaction strategy, which lead the system to its limits.

6.2.3 Physicality of items

The physical behavior of objects is an important factor in designing digital tabletops. Agarawala et al. [1] argued already, that adding physics to a system induces a more realistic, continuous and analog interaction feel. By reason of this, all items such as the colored shapes, the bubbles and the bins have an inertia behavior, which allows to toss the digital items across the table by just poking it. Participants were favorably disposed towards this physical behavior. Even though, some changes could improve both interfaces. Three participants stated independently that the speed of the items is too high. This was once again showed in the data set of $T10$. This participant struggled highly with the physical behavior of shapes and bins in the Bin condition, which lead to an increased task completion times. As he tried to hole the shapes into the bin, he nudged the object with his fingers. The major problem was that the objects exceeded the target due to high speed and had to be grouped again.

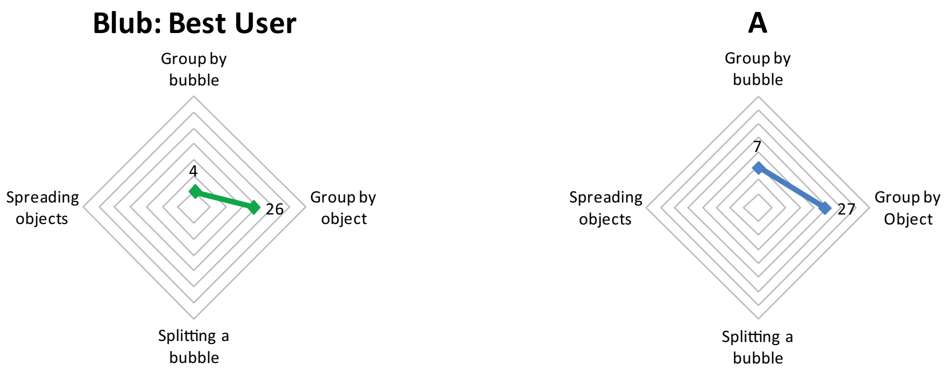
6.2.4 Start Setup

The start setup of the grouping phase was consistent across participants. For the regrouping phase, the position of the objects was dependent on the result of the grouping phase. The main difference between these two phases was that objects were possibly superimposed in the regrouping phase, but not in the grouping phase. This lead to higher task completion times as already shown in Section 5.10.1. This effect is particularly pronounced in the Blub condition. Participants interacted 26 seconds faster in the grouping than in the regrouping phase by using the Blub interface. One possible explanation is that structuring required perhaps more effort in the regrouping phase as objects were overlapped and participants needed to get an overview first. The question is if that is the reason, why is the difference between grouping and regrouping phase in the Bin condition just one second?

6.2.5 Interaction Types

User profiles of the average best and worst user were created in order to get an impression of which operations accelerate and which slow down the grouping task. Therefore, the interaction profiles (see Section 5.10.3) of the respective best and worst ten trials, balanced between grouping and regrouping phase, were aggregated and averaged.

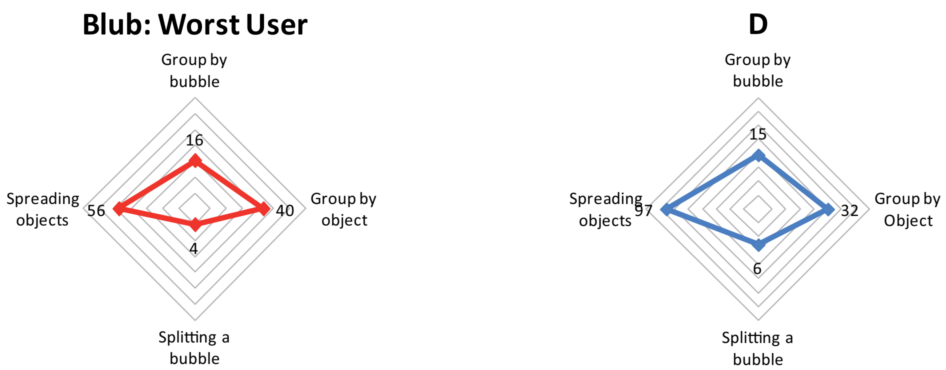
Figure 6.5 shows the averaged interaction profile of the best ten trials in the Blub condition. This profile has many parallels with interaction type A. The number of the executed operations in each category only differs a little. It can therefore be concluded that interaction type A was a very fast one. This is true, as type A had the best performance with 48 seconds.



(a) (b)

Figure 6.5: Blub: (a) User profile of the best 15% of trials. (b) Corresponding interaction type A with an average task completion time of 48 seconds.

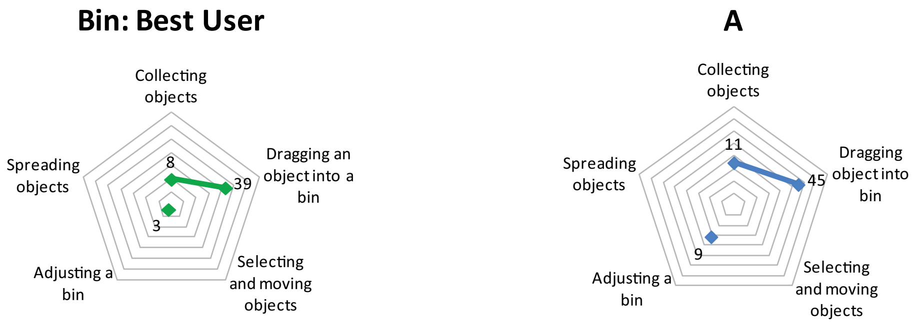
The average worst user in the Blub condition tried out all different operations (see Figure 6.6). Comparing these with the defined interaction types shows that interaction type D is similar to this profile. This indicates that type D was the slowest one, which is the case.



(a) (b)

Figure 6.6: Blub: (a) User profile of the worst 15% of trials. (b) Corresponding interaction type D with an average task completion time of 125 seconds.

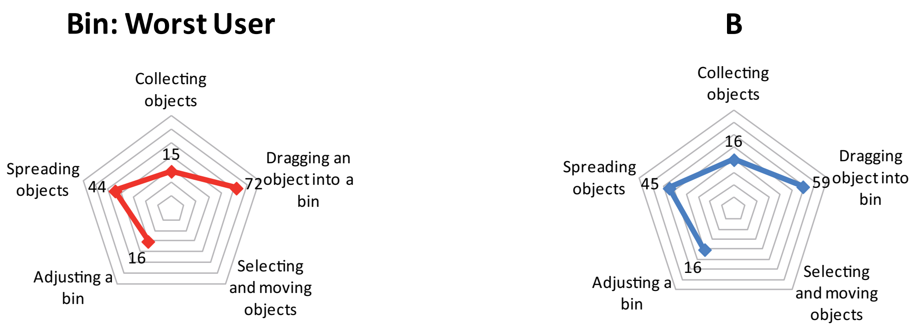
According to Figure 6.7, the best user in the Bin condition only collected objects, dragged objects into a bin and adjusted a bin. The pattern looks similar to that in interaction type A. Although, the average best user executed generally less operations. These differences result from the aggregation of the best trials, as some of them belonged to type D or H, which are simpler due to reduced number of various operations. Moreover, interaction type A had an average task completion time of 80 seconds. Some other interaction types were faster. The trials (22), which belong to type A vary a lot in their task completion times, which is the main reason that interaction type A looks like the best user profile for Bin, but is still slower than other interaction types.



(a) (b)

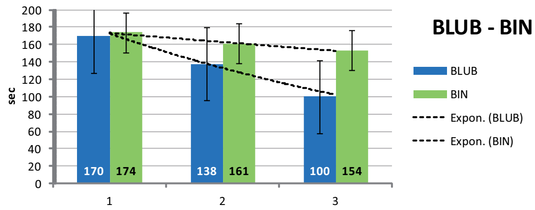
Figure 6.7: Bin: (a) User profile of the best 15% of trials. (b) Corresponding interaction type A with an average task completion time of 80 seconds.

Interaction type B is the counterpart of the average worst user profile. As Figure 6.8 illustrates, the number of operations only differs slightly. Section 5.10.3 depicts the task completion times of all interaction types in the Bin interface. In accordance with that, the most similar type of the averaged worst user profile is the one, who had the slowest performances with 118 seconds.

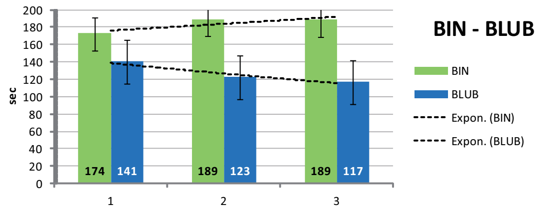


(a) (b)

Figure 6.8: Bin: (a) User profile of the worst 15% of trials. (b) Corresponding interaction type B with an average task completion time of 118 seconds.



(a)



(b)

Figure 6.9: Average trial times, standard deviation and exponential tendency across passes for balanced conditions. (a) Participants started with the Blub interface. (b) Participants interacted with the Bin interface first.

To conclude, the best and worst user performances were considered and compared with the defined interaction types. For each best and worst interaction profile a corresponding interaction type was found. Concerning the task completion times, in three of four cases this interaction type had the slowest or fastest performance. Nevertheless, the averaged best user profile of the Bin condition shows yet again that an interaction type indicates not always good are bad performances. The user performance is still dependent on some other factors.

6.2.6 Learning effects

A balanced within-subjects design was used in order to avoid strong learning effects. Thinking back to the learning curve across passes in Figure 5.3b, participants interacted almost equally long during the passes of the Bin condition. By using the Blub interface, they became faster. In Figure 6.9 the three passes are shown for both groups of participants, the ones, who started with the Blub interface and the others, who tried out the Bin interface first. The first group had a decreasing trend line in both conditions. Between the first and the last pass, they reduced their completion time by more than one minute in the Blub condition and around 20 seconds in the Bin condition. In contrast to that, participants, who used the Bin interface first, became even slower in the Bin condition, but acted faster right from the start in the Blub condition than the other group of participants. Thus, the learning curve is flatter, but still present.

So, the data suggests, that Blub was easier to understand, as those who used Blub first had a stronger learning curve. This goes hand in hand with the results of both questionnaires. In the AttrakDiff, the pragmatic quality was rated higher and so participants described the Blub interface as more *practical*, *straightforward*, *clearly structured* or *manageable*. This was also confirmed in the SUS, as participants thought Blub was easier to use than Bin (Blub: $\bar{s_3} = 4,67$, Bin: $\bar{s_3} = 4,50$). In conclusion, one possible explanation for the differences in the task completion times between the groups is that participants, who tried Blub first, felt more confident with the system and touch technology, which lead to their decreasing times in the Bin condition. And those, who started with the Bin interface were overstrained with the variety of interaction techniques and struggled with touch input.[1]

[1]Statistics have shown that half of all participants were familiar with touch input as they used touch devices frequently[2] (see Section 5.8).

6.2.7 Effect of fatigue

The whole procedure took 60 minutes and was exhausting for most of the participants. Especially the sitting posture in front of the digital tabletop was strenuous for some of the participants during the grouping task. By reason of this, there was a short break between grouping and regrouping phase and participants were asked to relax for one minute between the single passes. Three participants showed an increasing task completion time during the passes in the Bin condition. But all of them became faster in the Blub condition. $T10$ and $T14$ used the Bin interface first, $T13$ started with the Blub interface. So, no reliable conclusions concerning effects of fatigue can be drawn from these comparisons. Nevertheless, video recordings of $T10$ show that this participant had serious problems with the ergonomic comfort of the digital tabletop as he stood up during the three passes and completed the tasks in a standing posture. He also stated that he was not used to this posture. Maybe this physical effort is responsible for the difference of more than one minute between first and last pass in the Bin condition of $T10$.

6.3 User Preferences

Section 5.10.2 illustrated first results concerning user preferences. The two questionnaires SUS and AttrakDiff™ as well as the final interview were used in order to figure out, which aspects of the Blub and Bin interface were experienced positively and which aspects could be improved.

One research question was to find out which interface users prefer and what the reasons are therefore? The main hypothesis was that participants prefer the Blub interface. The next sections cover different aspects, in which the Blub and the Bin interface distinguish. These include simplicity, complexity, learnability, integrity of functions and attractiveness.

6.3.1 Simplicity

The simplicity of the interaction concept correlates with the user's preference. In the interview, nine of twelve participants described independently the Blub interface as simple, intuitive, plausible or more practical. Results of the AttrakDiff™ show, participants described Blub as *simpler*, more *straightforward* and *clearly structured* than the Bin interface. This goes hand in hand with the results of the SUS concerning the statement *"'I thought the system was easy to use."'* with an average rating of $\bar{s_3}(12) = 4.67$ for the Blub interface. In contrast to that, the rating for the Bin interface was averaged with $\bar{s_3}(12) = 4.17$, which is still a good rating.

The Blub as well as the Bin interface were generally perceived as simple. Anyhow, Blub was easier to understand for the participants. If this would be prooved in a long-term evaluation, results would may differ as participants had more time to understand both interfaces in all details.

6.3.2 Complexity

In the AttrakDiff™, the Blub interface was characterized as more *straightforward*, *clearly structured* and *manageable* than the Bin interface. The Bin interface was described as more complex than the Blub interface by three participants in the final interview. There are various reasons for this perceived complexity.

For example, the number of operations alone indicates that Bin is complexer than Blub. In the Bin interface, there are three different ways to add an object to a bin. Users can drag the object directly into the bin or they move the bin above one or more objects and collect those or they select objects with the lasso tool and move them into the bin. The Blub interface has only two possibilities, whereby these are relatively similar, as users either drag an object in the near of another object and bubbles merge or they move a bubble and release it and the bubbles merge. Another issue is, that users have the possibility to adjust a bin's shape by manipulating the eight handles of the boundary. A bubble has a flexible boundary, but does not allow the user to make any modifications of the contour directly. Nevertheless, both designs are justified. Participants made a lot of recommendations with regard to the adjusting of a bin in the final interview. One suggested smaller handles, as he thought this would help in getting a better overview of the bin's content. Before realizing this, the user's finger should be taken into account, as too small handles are not appropriate for all users hands (compare Fat Finger Problem [62]). Another point is the number of handles. In accordance with the participants, four handles will be enough. Another idea is to let users create handles on their own, for example by holding a finger on the specified point on the contour. Instead of spreading objects in a bin, participants would like to resize the bin by doing a pinching gesture. A further point, which could be improved easily is that the bin's contour can be dragged to the boundary of the surface as currently there is some offset in between the contour and the edge of the touch surface due to the position of the handles. Participants also described the Bin interface as more *cautious* in the AttrakDiff™. This was also demonstrated in some of the video recordings as some participants ($T4$, $T10$) were very careful in the interaction. One possible explanation is the smaller size of objects, as objects inside a bin are resized and the position of the handles is relatively close to each other in the start setup.

To sum it up, Blub is easier to learn, but provides less freedom in interaction. Bin is more complex, needs some more time to get familiar with it, but has some additional functions such as the resizing mechanism for saving space inside a bin, which were very well accepted by the participants. Despite, participants preferred the Blub interface in this study. Long term evaluation may show different results as users perhaps require some more features depending on the context.

6.3.3 Learnability

The results of the SUS showed that participants found both interfaces easy to learn as they rated *"'I would imagine that most people would learn to use this system very quickly."'* for the Blub with $\bar{s_7}(12) = 4.67$ and for the Bin interface with $\bar{s_7}(12) = 4.58$. Only one participant ($T7$) was unsure concerning the learnability of both interfaces. Troubles with coordination and high usage of physicality during the grouping task could be the reason for the bad rating in the Blub interface (see Section 6.2.3). In the Bin condition, this participant had big problems with the lasso tool. The results of easy learnability had also been confirmed by the interviews, in which four participants emphasized one more that both concepts were easy to learn.

6.3.4 Controllability

In the final interview, participants did not agree about the controllability of the Bin interface. Results of the SUS depicted that participants agreed more with *"'I found the system very cumbersome to use."'* in the Bin ($\bar{s_8}(12) = 2.17$) than in the Blub ($\bar{s_8}(12) = 1.42$) interface. One possible explanation is that the bubble metaphor gives a more realistic feel to interaction than the container metaphor. Better controllability correlates also with easy handling of an interface as already depicted in Section 6.3.1. Despite this, an interface's complexity implicates an increased controllability, as users have more freedom in interaction, but a harder handling, as it is more demanding.

In accordance with these results, controllability means also an ease of use. An easy understandable concept with a limited number of functions will enhance the fun factor particularly during the first interaction with it, as users do not have to care about complex interaction techniques. Participants also stated, that the interaction with Blub made much more fun than with Bin.

6.3.5 Integrity of functions

In correspondence with the participants, functions were better integrated in the Blub than in the Bin interface. The statement *"'I found the various functions in this system were well integrated."'* was rated with $\bar{s_5}(12) = 4.42$ for the Blub and with $\bar{s_5}(12) = 3.83$ for the Bin interface. Especially four participants ($T3$, $T6$, $T15$, $T10$) found that the function integration of the Bin interface can be improved. The reasons therefore may result from problems while executing special operations. For example, $T6$ struggled with spreading objects while he was moving a bin as this had triggered the spreading operation. For example, if a user tries to move a bin with two or more fingers, spreading objects can be triggered, which mostly confuses the user. $T6$ also suggested further buttons for further functionality in the Bin interface. Another issue was the activation of the lasso tool (compare Section 6.2.1). As $T10$ activated the lasso once, the interaction mode was changed, bins were locked and handles were disabled until he moved the lasso selection. This was not easy to understand for the participant, which may is the reason for his bad rating concerning the integrity of functions. There were no specific problems in the trials of $T15$. Even though, this participant found the Bin interface difficult and complicated.

Consequently, the integrity of functions is an important issue for rating an interface. However, the perceived quality of function integration is also dependent on the right usage of those. A more detailed description could help the user to understand all of the operations, if the design rationale of operations is not intuitive and self-explanatory. Anyhow, an improvement of the mode switches could enhance the user experience of both interfaces.

6.3.6 Attractiveness

Looking back to Section 5.10.2 reminds that the attractiveness of the Blub interface was higher rated than that of the Bin interface. Participants described Blub as more *pleasant*, *attractive*, *likable* and *inviting*. In the interview, participants argued that the physical behavior is better integrated in the Blub condition, as objects can stick in a bubble after tossing them. At this point, it is important to note, that objects had the same physical behavior in both conditions. Participants meant the bubble metaphor by saying that the Blub interface has a better physical behavior. The continuous merging of bubbles during executing a dragging operation gave the interface a more realistic feel. Even though, some participants argued that the speed of objects was too high and objects should be throttled down drastically if they collide with any other bubble. Sure, this could enhance the user experience once more. Participants also liked splitting a bubble. Some of the participants complained about the missing splitting functionality in the Bin interface. Participants rated Bin more *motivating*, but found Blub more *challenging*. At first sight, this looks like a discrepancy. But indeed, these two factors raise two different things. Motivation can be interpreted as the amount to which users like to interact with an interface and challenge is concerned with the fact, that something is new. The container metaphor is present every day. Things were put into boxes, files were dragged into folders and rooms are still parts of a house. The bubble metaphor is holed up in phenomenas like water drops or soap bubbles. Maybe that is the reason why participants perceived the Blub interface more as a challenge, as they were fascinated by the usage of this metaphor.

Attractiveness is an important aspect for most of the interfaces. In this study, participants experienced the Blub interface as more attractive. The main reasons therefore were the realistic feel (compare Agarawala et al. [1]) and the metaphor behind the interface. There is still an ample scope in either the Blub or the Bin interface for further improvements especially concerning specific functionalities. Nonetheless, attractiveness has an immediate effect on the preferences of the users.

6.4 Interaction Strategies

Section 5.10.3 presented four interaction types for the Blub and eight interaction types for the Bin interface. As already mentioned, the defined interaction types do not always indicate one specific interaction strategy. The qualitative analysis of the video recordings showed that same interaction strategies were present across the different interaction types. So, an interaction strategy can be defined as a series of operations.

The following sections give an overview about the different interaction strategies. Here, the main intention was to gain knowledge about the differences in the applied interaction strategies between Blub and Bin interface? The main hypothesis was that the interaction strategies differ between using Blub or Bin interface. This can be caused by the two different metaphors behind the interfaces.

6.4.1 Interacting with Blub

The interaction strategies of Blub reflect partly its interaction types. Types A, B and C can be found in the following strategies: *Selective Assorting*, *Tailoring* and *Getting an overview*. Interaction type D is a mixture of the latter two and strategy *Tossing to the edge* is a specific type of the first one.

Selective Assorting

This interaction strategy is strongly related to interaction type A and was mainly used in the grouping phase. By applying this interaction strategy, participants worked very target-oriented. One object or bubble was directly dragged to the target bubble. Participants began selectively either with one color and grouped all objects from this color or started from one specific position and grouped all objects to their specific colors.

For grouping objects, *Selective Assorting* was the most prominent strategy and also served as the basis for all other strategies. This interaction strategy is simple and fast.

Tossing to the edge

Participants tossed objects to the edges of the surface in order to group them by color. This was a very fast technique, as objects did not bounce back and sticked at the edge. Only some final adjustments were necessary when objects missed their targets.

Tossing to the edge is a special type of *Selective Assorting* and uses the advantages of physicality.

Tailoring

As an enlarged version of the *Selective Assorting*, this interaction strategy addressed primarily the regrouping phase. This strategy was especially applied in the end of the grouping phase were final sorting was necessary. For example, if groups of two different colors were inside one bubble, participants were able to separate these groups easily by cutting them (see Figure 6.10). In contrast to the base interaction strategy *Selective Assorting*, objects were often cut away instead of dragging them away. The main advantage of this interaction strategy is, that multiple objects can be split from a bubble at once.

Tailoring was particularly of interest in the regrouping phase, as splitting a bubble was more often necessary than in the grouping phase.

Getting an overview

This interaction strategy was only applied in the regrouping phase. Participants spread objects in order to get an overview in the beginning. The overview was convenient for the whole grouping procedure and made *Selective Assorting* easier. A special type of this interaction strategy was used by $T6$ and $T15$, as these participants grouped all objects into one bubble and executing afterwards the spreading operation.

(a) (b) (c)

Figure 6.10: Tailoring: (a) Spreading objects inside the bubble. (b) Pushing the cutter button and drawing a free-form stroke. (c) Splitted bubbles.

This strategy was as often as *Tailoring* applied, but it's important to note, that this strategy addresses another issue. One advantage of this strategy is that the general arrangement of the objects is provided.

6.4.2 Interacting with Bin

In the Bin condition, interaction strategies did not correlate to the same extent as in the Blub condition with the defined interaction types. Rather, each interaction strategy describes a completed interaction sequence within a trial. The interaction strategies are called *Dragging into a bin*, *Holing objects*, *Dragging from bin to bin*, *Accumulating and Collecting*, *Accumulating, Selecting and Moving Objects*, *Accumulating and Adjusting* and *Getting an overview*.

Dragging into a bin

This is the simplest interaction strategy. Participants dragged the objects into the corresponding bin. Interaction type F was limited to this interaction strategy. All other types used this as base strategy, but applied also some other strategies. Figure 6.11a shows a result for a trial of interaction type F. Typical is that the shapes of the bins were not modified.

Dragging into a bin is easy to learn for users. Trials using only this interaction strategy had the lowest task completion times with 57 seconds on average.

Holing objects

Holing objects is a special type of *Dragging into a bin*. By using this interaction strategy, participants take advantage of the physical behavior of the objects. The major problem was that objects were not throttled down if they passed a bin. Sometimes objects overshot their target bin and needed to be moved again into the bin.

Some improvements concerning the physicality could enhance this interaction strategy, as it can be described as playful.

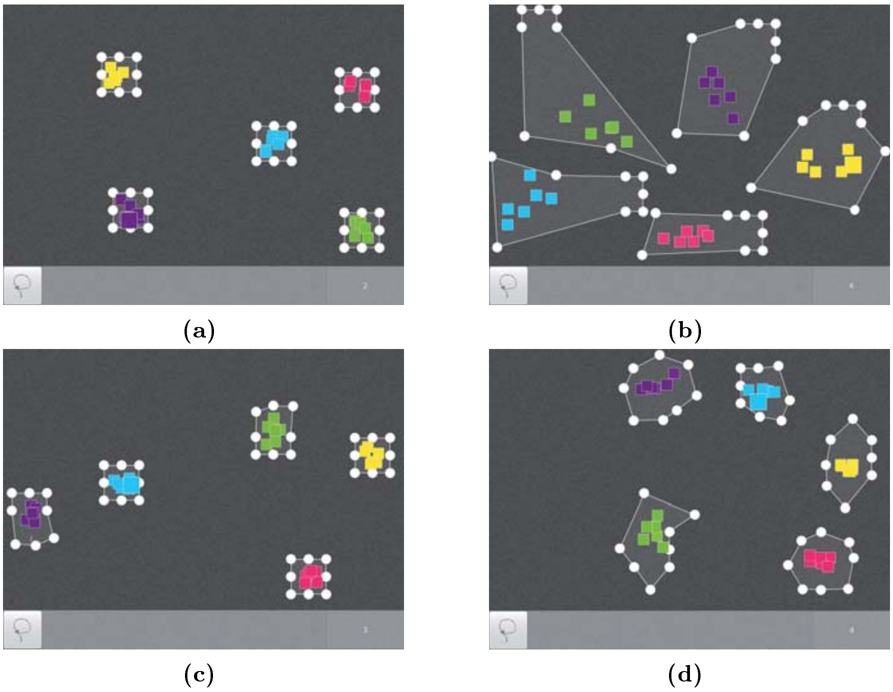


Figure 6.11: Typical results for exclusive usage of (a) *Dragging into a bin*, (b) *Dragging from bin to bin*, (c) *Accumulating and Adjusting* and (d) a mixture of the strategies.

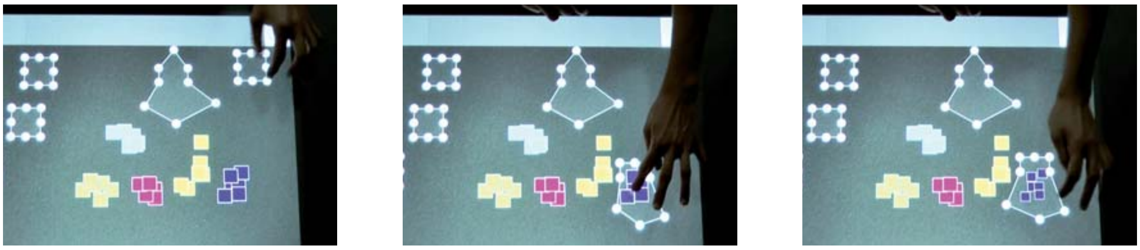
Dragging from bin to bin

In the regrouping phase, some participants dragged directly objects from bin to bin. In contrast to strategies, in which objects were dragged out before they were binned again, this strategy saves one way of interaction. One participant used the possibility to adjust bins in order to reduce the interaction paths between two bins. The result of this trial is shown in Figure 6.11b.

Dragging from bin to bin was applied successively for the bins. Participants sorted the objects of one bin, before they started with another bin. Advantageous in this interaction strategy is, that one step in the interaction is saved due to the direct movement from bin to bin.

Accumulating and Collecting

A frequently applied strategy was to accumulate and collect same colored shapes, which was applied in grouping as well as regrouping phase. Therefore, participants started to create one group for each color. As soon as one group was complete, they dragged the bin over and objects were collected (see Figure 6.12). One problem was that the group had to be smaller than the Bin, otherwise objects were not collected and had to be dragged separately into the bin. This interaction strategy can be found in half of the interaction types (B, C, D, G).

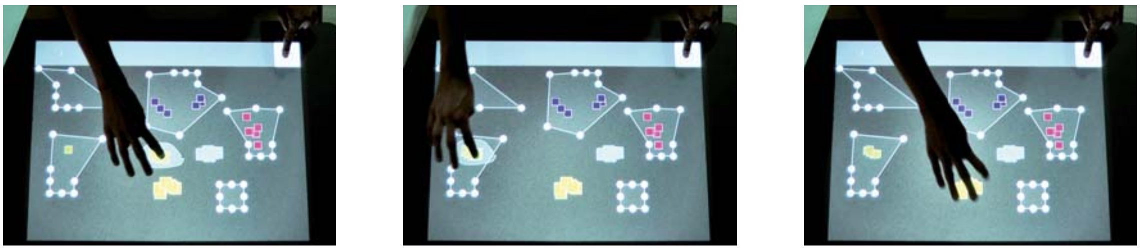


(a) (b) (c)

Figure 6.12: Accumulating and Collecting: (a) Accumulated objects. (b) Dragging bin over objects. (c) Releasing bin and resizing objects.

Accumulating, Selecting and Moving Objects

Participants used the lasso tool for binning one or more objects (see Figure 6.13). Two problems can be identified concerning this strategy. The lasso selection has to include completely all objects for selecting them. The second problem is, that scattered objects can be selected, but if the bin is smaller than the selection, objects stay outside the bin's boundary.



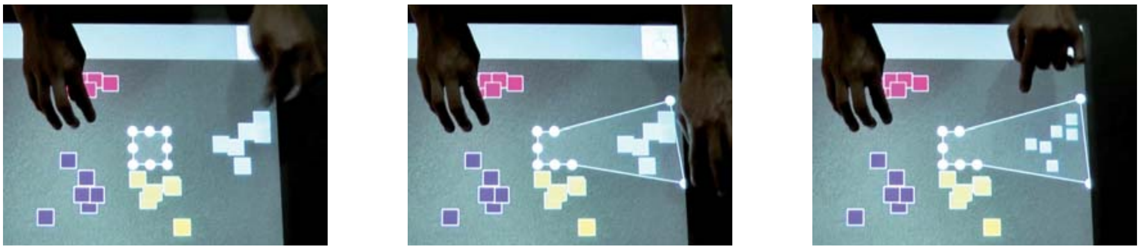
(a) (b) (c)

Figure 6.13: Accumulating, Selecting and Moving Objects: (a) Drawing a free-form shape. (b) Dragging selected objects into the bin. (c) Releasing selected objects and resizing objects automatically inside the bin.

Interaction type C, D, H make use of this interaction strategy. A lower sensitivity concerning the objects boundary by making a lasso selection and an automatic movement of objects into the bin while releasing could improve this interaction strategy.

Accumulating and Adjusting

The third possibility to bin accumulated objects is to adjust the bin's boundary. One major problem in this interaction strategy is that the corresponding bin is not always next to the accumulated objects. Therefore, either the bin is moved to the objects or the bin's handles are dragged at the risk of overlapping bins. The purpose of adjusting was mostly to make final corrections, as some objects were not correctly binned (see Figure 6.11d). In some trials, *Accumulating and Adjusting* was used together with collecting or selecting and moving objects. Figure 6.14 shows how accumulated objects can be binned by adjusting the bin's boundary. This strategy can be found in interaction types A, B, C and E.



(a) (b) (c)

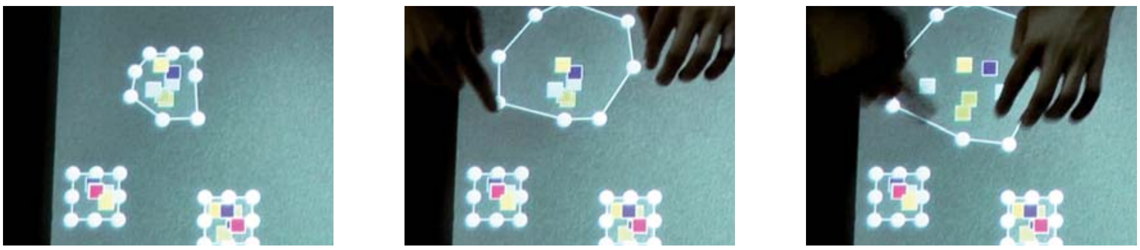
Figure 6.14: Accumulating and Adjusting: (a) Accumulated objects. (b) Dragging a handle to adjust the bin. (c) Adjusted bin with resized objects.

Accumulating at the edge

This interaction strategy was applied in combination with the last three ones. The specialty of this interaction strategy is that participants tossed items to the edge for some pre-sorting. Afterwards, they binned these objects by collecting, using the lasso or adjusting the bin. One big problem was, that bins had not reached the edge of the surface, which disposed some final adjustments.

Getting an overview

For some participants, it was important to have an overview in the regrouping phase. Instead of using the spreading objects technique, participants applied a different strategy. They began with enlarging the bin so as to provide more space and dragged the superimposed objects apart (see Figure 6.15). Automated adjustment of the bin's boundary could improve the original spreading functionality strategy rapidly, but should be considered carefully.



(a) (b) (c)

Figure 6.15: Getting an overview: (a) Superimposed objects. (b) Enlarging bin to provide space. (c) Dragging superimposed objects apart.

Table 6.1: BLUB: Description of gestures.

BLUB	Single finger	Multiple fingers
One hand	**Drag single object.** *Group:* Dragging an object to a bubble. *Ungroup:* Pulling an object apart from a bubble. **Toss single object.** *Grouping:* Tossing an object into a bubble. *Ungroup:* Tossing an object away from a bubble.	**Drag objects with individual fingers.** *Group:* Drag individual objects with separate fingers of one hand to a bubble. *Ungroup:* Pull individual objects with separate fingers of one hand apart from a bubble. **Pull thumb and index finger apart.** *Spread objects:* Make a pinching gesture to spread objects inside a bubble. **Splay fingers.** *Spread objects:* Open the hand in order to expand the boundary.
Two hands	**Drag two objects with pointer fingers.** *Group:* Drag two individual objects to a bubble. *Ungroup:* Pull individual objects with the index fingers apart from a bubble in two different directions. **Pinch a pile.** *Group:* Pinching a group of pieces together. **Hold the button. Draw a free-form stroke.** *Split a bubble:* Hold the cutter button with one hand, while the other hand splits the bubble by drawing a free-form stroke. **Pulling index fingers apart.** *Spread objects:* Make a pinching gesture with the two index fingers to spread objects inside a bubble.	**Pinch a pile.** *Group:* Pinching a group of pieces together. **Add / remove from selection.** *Ungroup:* Pull an object out of the bubble with one hand, while the other hand is holding the bubble.

6.5 Gestures

Results concerning bi-manuality and multiple finger input were shown in Section 5.10.4. According to these, participants used both hands more often in the Blub than in the Bin condition. There were no specific findings concerning multi-finger interaction. As the study was conducted on a multi-touch table and the original work of Bubble Clusters [61] was done for mouse input, one of the research goals of this study was to find out if Blub works on touch-sensitive surfaces. A further research question was, if Blub or Bin interface is more appropriate for bi-manual and multi-finger interaction?

To answer this question, Table 6.1 and 6.2 show descriptions of applied gestures. These tables are based on the work of North et al. [45], which appreciated a grouping task with digital and physical objects on a tabletop. The following sections introduce the three most interesting gestures, which were observed. Each section gives a short description of the gesture, discusses the advantages and disadvantages and shows the scope of application.

Table 6.2: BIN: Description of gestures.

BIN	Single finger	Multiple fingers
One hand	**Drag single object.** *Drag object into bin:* Drag an object into a bin. *Drag object out of bin:* Drag an object out of a bin. *Collect objects:* Move a bin over one or more objects and release it. *Adjust a bin:* Manipulate one handle of a bin to adjust it's shape. **Toss single object.** *Drag object into bin:* Toss an object into a bin. *Drag object out of bin:* Toss an object out of a bin.	**Drag objects with individual fingers.** *Drag object into bin:* Drag individual objects with separate fingers of one hand into a bin. *Drag object out of bin:* Drag individual objects with separate fingers of one hand out of a bin. *Adjusting a bin:* Manipulate multiple handles with separate fingers of one hand for resizing the bin (mostly in parallel direction).
Two hands	**Drag two objects with pointer fingers.** *Drag object into bin:* Drag two individual objects into a bin. *Drag object out of bin:* Drag two objects with the index fingers out of a bin in different directions. *Adjusting a bin:* Move two handles of a bin with the index fingers in different directions. **Push the button. Draw a free-form shape.** *Selecting and moving objects:* Push the lasso button with one hand and select objects with the other hand. **Pulling index fingers apart.** *Spread objects:* Make a pinching gesture with the two index fingers to spread objects inside a bin.	**Drag multiple objects with individual fingers.** *Adjust:* Move handles of a bin with individual fingers of both hands in different directions. **Add / remove from selection.** *Drag object out of bin:* Pull an object out of the bin with one hand, while the other hand is holding the bin.

6.5.1 Pinch a pile

To pinch a pile, individual fingers of one hand touch different objects and contract. The main advantage of this gesture is, several objects can be grouped at once. Moreover, it is not just appropriate for multi-touch, it needs multi-touch. One disadvantage may is that it requires a little practice and skill before it can be applied correctly. In the study, this gesture was used for grouping objects in one bubble (see Figure 6.16a). Besides, it could be interesting for grabbing items with the fingers and spreading them out on a different position on the table or even on a different surface, as the user just needs his fingers and no physical object for doing this.

6.5.2 Splay fingers

Tightening and splaying fingers was mainly executed instead of the pinching gesture for spreading objects. The metaphor behind this gesture is to hide one's fingers first in order to show it afterwards. This reflects the spreading of objects as all superimposed objects could

(a) (b) (c)

Figure 6.16: (a) Pinching a pile by using the Blub interface. (b) Splaying fingers for enlarging the bubble. (c) Dragging multiple objects with individual fingers.

be spread out after splaying the fingers. In the Blub condition, participants also tried to stretch the boundary of the bubble by splaying fingers (see Figure 6.16b). This idea would allow the user to adjust the bubble's boundary with his fingers. But what if the splayed fingers do not reach the contour of the bubble as the bubble is too large? This could be one disadvantage. Furthermore, this gesture needs some practice and skill from unexperienced users before it can be exactly executed.

6.5.3 Drag objects with individual fingers

This gesture allows to pull several objects out of a bubble or bin at once (see Figure 6.16c). By applying this gesture in the grouping task, participants acted very target-oriented and were pretty fast. They often took same colored objects out of a bubble or bin and made a heap of them. This gesture also requires training so as to take full advantage of its benefits and could especially be interesting for regrouping tasks or even instead of the splitting gesture in the Blub interface. In contrast to mouse input, touch input enables the user to interact with both hands. This allows the user to group or ungroup more than one object to or from a bubble by using the Blub interface. Perhaps, this makes the splitting tool unnecessary. Even though, the relative position of the objects will not remain untouched, which could be a disadvantage.

6.6 Design Implications

To summarize the variety of ideas, which are resulting from this discussion, the next sections present some design implications concerning the visualization and the interaction techniques of Blub and Bin.

6.6.1 Blub

The design rationale in Section 4.1 has shown that Blub is mainly based on the bubble metaphor and is bionically inspired. The major foundations are the *Gestal law of Proximity* and *Good Continuation* [56].

Visualization

The performance of the real-time bubble visualization can be improved in future interfaces as the computational effort is currently high and the complexity of the mathematical formula raises with the number of objects in a bubble. Dragging an object inside a bubble forces the system to calculate the contour again and again, which leads to latency. One possible solution is to outsource this calculation to the GPU.

Physicality

Concerning the physical behavior of objects, participants complained about the high speed, as objects overshot their marks while being tossed. Lowering the speed could improve the performance of users. Another idea is to use Superflick [48], which is a throwing-based interaction technique. Superflick adds a correction step to the physical behavior in order to improve particularly the accuracy of small targets. For the Blub interface, throttling down objects while merging with a bubble would furthermore raise the user experience.

Group by bubble

A bubble is dragged in order to move a number of objects over large distances. To make this interaction technique a little more elegant, other bubbles could move apart, while the dragging operation is executed (compare Robertson et al. [50]).

Splitting a bubble

As shown in Section 6.5.3 multi-touch allows users to drag multiple objects with individual fingers in parallel. This raises the question if *Splitting a bubble* is still necessary. The main advantage of using the cutter is that the relative positions of the objects remain unchanged. Nonetheless, if this interaction technique is kept in future designs, the mode switch should be taken into account. According to a study of Frisch et al. [17], users hold intuitively the background in order to activate a certain mode. This sounds good as long as one single user touches the table. In a collaborative setting, a physical token could be a possible solution. Another possibility is to hold the bubble with one hand, the system freezes a region around this bubble and the user can split the bubble with his other hand, even if other users were interacting on the table.

Spreading objects

The gesture for spreading objects was not clear for all of the participants. The splaying of fingers can be an alternative gesture (see Section 6.5.2).

Adjusting a bubble

Some mechanism for adjusting a bubble could add some complexity and enhance the controllability of Blub. One idea is to let users create handles on their own, for example by holding a finger on the specified point on the contour. Another possibility is to stretch the contour like an elastic rubber band by splaying the fingers.

6.6.2 Bin

In Section 4.2, the Design Rationale of Bin was introduced and depicted that the principle is based on the *Container-Image Schema* [32].

Visualization

A reduction of the handles from eight to four handles could simplify the shape and subsequently the interaction with the Bin interface. To modify the shape of a bin, resizing by a pinching gesture would be much more easy to understand by the participants. But all those improvements should be considered carefully, as reducing the complexity could also mean lowering the user experience as users have less freedom in interaction. Another thing is, bins should reach to the edge of the interface. This could be particularly beneficial for the interaction strategy *Accumulating at the edge* (see Section 6.4.2).

Physicality

The physical behavior of objects could simply be improved by lowering the speed of objects. Like playing golf, holing by tossing an object could be improved by giving the bin a third dimension. For example, if an object is holed, it can not get out of it and bounces back from the bin's edges as long as it has speed.

Selecting and moving objects

As already discussed in Section 6.6.1, the button for changing the mode should be reconsidered. Furthermore, there should be an option to disable the lasso as this is currently only possible by dragging and releasing the selection. Similarily to *Splitting a bubble* (see Section 6.6.1), one idea is to freeze a region by holding down with one hand and drawing a selection by the other hand. All those considerations become necessary if zooming and panning behavior is included.

Spreading objects

Spreading objects is difficult to understand in the current design as it is triggered by moving a bin with several fingers sometimes. To improve this interaction technique, the splaying fingers gesture (see Section 6.5.2) should be considered. An automatic adjustment of the bin's boundary could additionally improve the feedback for the user.

6.7 Summary

In Section 5.1, the five research questions and four hypotheses were formulated. The study results as well as the discussion gave an answer to these questions and verified the hypotheses. The following paragraph summarizes those results and depicts the main findings of the study.

H1: The bubble metaphor works as Blub on digital tabletops. This hypothesis was confirmed as 94% of the trials in the Blub condition were successfully completed.

H2: Bin speeds up the grouping task. There were different aspects, which influenced the user performances. Some of the participants struggled with the mode switches such as the cutter in the Blub or the lasso tool in the Bin interface. The performance of the real-time bubble visualization was another problem. Concerning the physical behavior of objects, participants complained about the high speed, as objects overshot their marks after they were tossed.

Task completion time between grouping and regrouping phase distinguished. This is due to the superimposed objects in the initial state of the regrouping setup. In addition, participants, who started with the Blub interface had a stronger learning curve in both interfaces. Concrete effects of fatigue were not found. Just the ergonomic comfort of the table was an issue for one participant. The main hypothesis that participants were faster in the grouping task by using the Bin interface was consequently disproved.

H3: The user will prefer Blub. As the discussion of the users preferences has shown, the Blub interface was perceived as simpler. The complexity of the Bin interface came along with the higher number of different operations, the adjustment of the boundary by the use of handles and the resize behavior of objects inside a bin. Participants found both concepts easy to learn. The integrity of functions was a big issue in the rating, which is the result of wrong usage of the interface. Participants had furthermore problems with the cutter and the lasso button as previously discussed. Participants found the Blub interface more attractive and challenging in opposite to the Bin interface, which was perceived as more motivating. In general, eleven of twelve participants preferred the Blub interface and so the main hypothesis that participants prefer the Blub interface was confirmed.

H4: There are differences between the interaction strategies by using the Blub and the Bin interface. The different interaction strategies of Blub and Bin were shown in Section 6.4. Some parallels in the interaction strategies were found for example, in strategies using physicality (Blub: *Tossing to the edge* (see Section 6.4.1) and Bin: *Accumulating at the edge* (see Section 6.4.2)) or getting an overview (Blub: *Getting an overview* (see Section 6.4.1) and Bin: *Getting an overview* (see Section 6.4.2)). The main hypothesis that the interaction strategies differ between using Blub or Bin interface was confirmed as the different metaphors initiated the participants to interact differently.

To sum it up, $H1$, $H3$ and $H4$ were confirmed and $H2$ was disproved.

Besides the analysis concerning *User Performance*, *User Preferences* and *Interaction Strategies* the used gestures in both interfaces were introduced and broken down to bi-manuality and multiple finger input. The three most interesting gestures *Pinch a pile*, *Splaying fingers* and *Drag objects with individual fingers* were further discussed and analyzed concerning their advantages and disadvantages and finally, their fields of applications in the Blub and the Bin interface were shown.

The last for Sections analyzed critically the Blub and the Bin interface. The major finding was that there is still some potential in improving both interfaces. Therefore, Section 6.6 established some design implications regarding the visualization, the existing and future interaction techniques and physicality.

Chapter 7

Conclusion

This work presented Blub and Bin, two interaction concepts for object and group manipulation on digital surfaces. A conducted user study showed that both concepts work in a simple grouping task. The bionically-inspired bubble principle of Blub was preferred by the users and speed up their performance. Interaction strategies had a higher variety by using the more complex Bin interface and were consequently simpler by the use of the Blub interface. There were no significant differences between the two interfaces regarding the use of multiple fingers or both hands for interaction. Nevertheless, participants had a tendency to act with both hands and multiple fingers in the Blub and with both hands and single fingers or one hand and multiple fingers in the Bin condition. To find out whether the preferred Blub interface could assist designers in managing their shared space, the following sections rate its support concerning *capturing the design process*, *linking related design knowledge*, *sharing design knowledge* and *reusing prior design artifacts*.

Support in capturing the design process

The big challenge in supporting the capturing of a design process is to provide tools for creating a clear overview of the produced material. The main foundations of Blub lie in the *Gestalt laws of Proximity* and *Unity* [56]. The combination of these two design principles allows designers to create a flexible spatial arrangement of design artifacts, while still having some structure in this chaotic space. Therefore, proximity can be used to express relationships between objects inside the bubble and unity, represented by the shape of the bubble, can *remind* the designer *by structure* [6]. This means, the form of the bubble alone indicates the project and designers find projects again more easily. In addition, the flexible spatial layout of a bubble allows to establish whole narrative strands, which can be used for presenting storyboards, to show design alternatives in parallel or to illustrate a whole design process of convergent and divergent thinking [12] (compare Figure 1.3). For example, a shared surface can be used to organize a variety of projects. If one design artifact is not part of a final design solution and got lost in the divergent thinking process, this artifact can be interesting for another project, Therefore, Blub gives the designer the freedom to easily drag this artifact to another project in order to display its new relationship. Furthermore, the use of a zoomable landscape can enrich this design space, as focusing on specific design artifacts would be possible. Otherwise, as a shared surface enriches the whole design environment, this focusing mechanism may interrupts other designers in their creative thinking process. To avoid such an effect, making another display (e.g. Tablet PC, Pad) to the region of focus, can be a possible solution (compare TEAM STORM [23]).

Support in linking related design knowledge

Two artifacts can either have a strong relation to another or not. Links in between artifacts open up the meaning and the importance of each of them [60]. This is important to understand a whole network of artifacts. Organizing artifacts of one design phase can be easily done by using spatial layouts. The main question is how can artifacts be connected across design phases. One possibility is to use the bubble's contour, for example by making some spatial aggregated groups of objects and dragging them next to each other in order to get a surrounding boundary. Another opportunity is to assign a specific region on the surface to one project and create some kind of design process flow (e.g. as stacked bubbles). Drawing explicit connections between bubbles is another alternative for visualizing the relations between two bubbles (compare Brainstorming System [29]). For a smoother representation, the visualization of Bubble Sets [13] should be taken into account.

Support in sharing design knowledge

The designer's skill of creating new fruitful ideas could be strengthened by visualizing a landscape full of flourishing ideas in his environment. Sliding through this landscape of design artifacts in a smart and proper way for gaining inspiration or getting an overview of a variety of projects in collaborative settings can be assisted by using this digital space. Blub would enable the designer to interact with his whole surrounding design space by just using his fingers and hands. This means that no additional tool is necessary and interaction can start immediately, which is one big advantage. Moreover, grouping artifacts by using multiple fingers and both hands will speed up this process, as the user study has shown. Currently, the creation of different bubbles or spatial layouts inside the bubble is possible. The usage of different colors for the surrounding boundaries of the bubbles (compare Flux (clusters) [8]) could furthermore improve the overview of a shared surface. Colors would help the user in distinguishing between different projects, as these can be described as nominal data [39]. Humans perceive the spatial position stronger than the color. If the shared space is big enough, the assignment of specific regions for different projects would assist the designers to get a better overview and to find artifacts again more quickly. By using Blub, the organization task is also supported by physicality. For example, designers can simply toss items to the bottom of a shared surface in order to make room for more relevant design artifacts. This ground of ideas can be used for later projects and serves as design ground. Blub provides a spreading mechanism for superimposed objects, which could be useful for getting an overview of aggregated objects. The smooth animation spreads all objects, adjusts the surrounding bubble and gives continuous feedback to the user. The only disadvantage by using this technique is actually that the original position can not be reconstructed. There is no backward functionality, which can be used to return to the old spatial layout. Future designers should think about that as currently information is getting lost. The results of the user study have shown that participants particularly liked the playful approach of the Blub interface. In turn, for a collaborative design setting this means, designers create a shared understanding more easily as they have fun by using Blub. As a consequence, the Blub interface supports *Reflection-in-Action* [51] as designers can directly interact with the visual design artifacts and are able to generate some kind of structure in the wealth of information.

Support in reusing prior design artifacts

In order to find design artifacts again at the right time, the design space has to provide a good overview or good interaction techniques for filtering artifacts. By using Blub, retrieving a single artifact is supported by the representation of the whole design space. For example, the form of the bubble's shape could picture the project, the project status or the type of project. A one-month project would have less design artifacts than a three-year project. The visual presence of a bubble is also influenced by the content of the artifacts itself. For example, designers use other artifact types for designing a new watch (e.g. images, sketches) than for producing a 3D animation (e.g. wireframe images, high quality renderings). The importance of single artifacts can be illustrated by its size. Large artifacts can indicate greater importance than small artifacts. In order to support the reuse of design knowledge, some kind of design ground at the bottom of the display could assist users in finding unused artifacts, which may have potential for another project, again. Moreover, a copy tool would allow designers to use knowledge across projects. Therefore, either a physical token or a simple gesture (compare Frisch et al. [17], Wobbrock et al. [63]) can be used. The latter one is more preferable, because the interaction will not be interrupted as the designer does not have to search the token in the physical environment. Another reason is that more designers can execute copy operations in parallel by using a gesture instead of a physical token.

Figure 7.1: A shared wall, full of sketches, design ideas and other informational artifacts [58].

Figure 7.2: Future Scenario: Shared digital wall organized by using Blub.

This work has shown that Blub can assist designers in organizing their artifacts on shared digital surfaces and provides support in each of the four defined requirements. This results especially from the *Gestalt law of Proximity* and *Unity* and the use of a touch-sensitive surface. Figure 7.1 shows the usual shared design space in comparison with a shared wall organized by Blub. Nevertheless, there is still some potential for improvements. So as to provide even a better overview over different projects or other groupings inside the design space, colored bubble boundaries could foster searching processes. As Blub is particularly developed for multi-touch displays, the splitting tool can be removed in order to reduce complexity in interaction. For example, users can extract more than one object from a bubble with their ten fingers. To raise the consistency of the interaction concept and to preserve spatial information, a backward spreading functionality should be considered. For organizing a large collection of artifacts, copy and remove functionalities can be interesting.

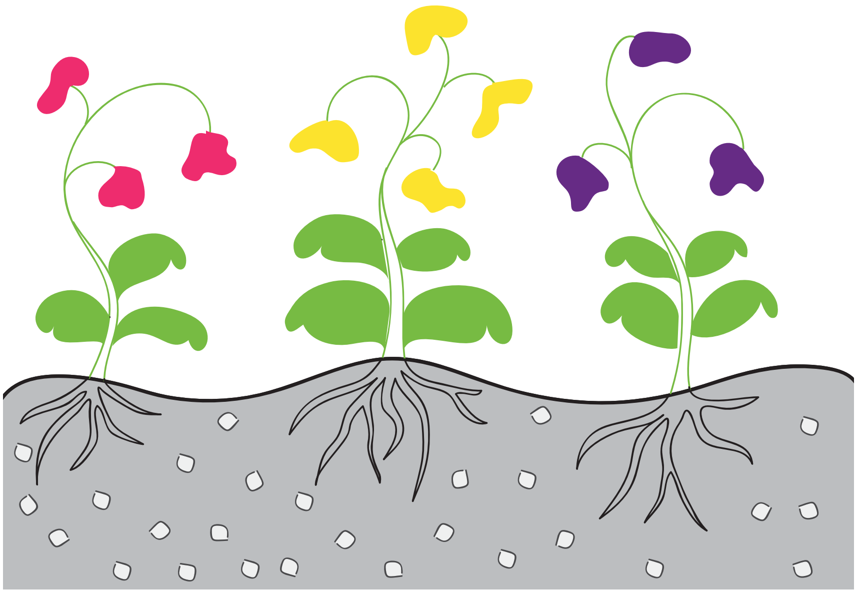


Figure 7.3: Shared design ground: Each flower represents one design process. The shared ground allows to use design artifacts from other design processes and enriches the environment.

The design process from the first idea to the design solution is like a flower. In order to save the life of such a flower, new ideas are constantly needed. These new ideas can be possibly found on a shared ground as illustrated in Figure 7.3. Consequently a shared space is indispensable in a designer's environment.

Chapter 8

Future Work

In consideration of using Blub for the discussion of design ideas or the reflection of design solutions, a setting of a digital tabletop and a large display could provide further advantages. For example, the tabletop can be used for getting an overview and the display for focusing on some details. As Figure 8.1 shows, each display has its own way for interaction. This is for providing a clear separation between the control of the displays. This holistic system intends touch input for the digital tabletop. As the main purpose of this system would be to reorganize a design space, an improved version of Blub would be suitable as interaction concept. Sifteos[1] [42] can be used for interacting with the display. The following sections present *ReSi* - an interactive remote control by using Sifteos.

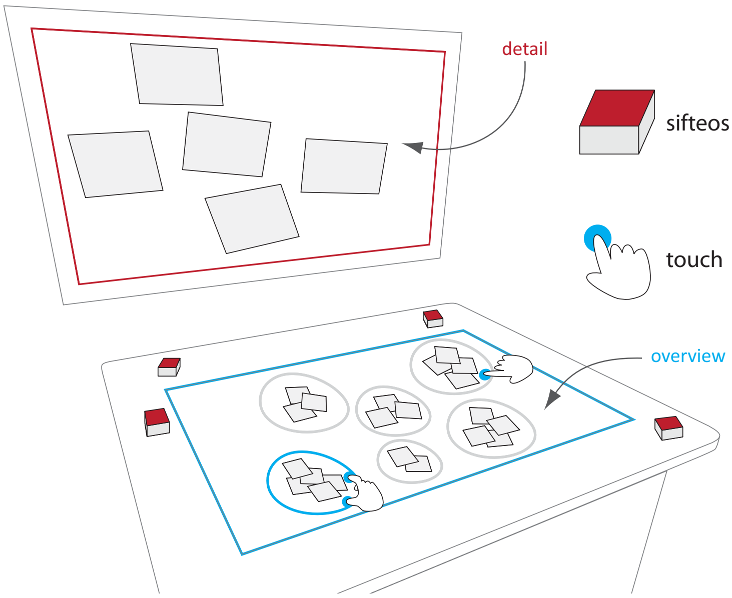


Figure 8.1: Holistic System

[1] *Sifteos* are small cubes with clickable, full color LCD displays and are usually used for gameplaying. For more information: http://www.sifteo.com

8.1 ReSi - Interactive Remote Control by using Sifteos

ReSi is a first approach of using Sifteos for controlling displays. The following sections present three ideas for the interaction with dynamic visualization by using this small cubes.

8.1.1 Snapshot Navigation

This interaction technique can be compared with the history tool of the Designer's Outpost [37]. The main intention is to save a whole visualization or a region of interest at specific points in time. At a later time, this timestamps can be used to reconstruct the development of a specific spatial arrangement. Figure 8.2 illustrates the procedure therefore. The current timestamp is displayed on the Sifteo. By rotating the cube, the next timestamp appears. If the preferred point in time is reached, the user presses the display and the visualization will be animated back to this status. The disadvantage of this interaction technique is that there is no visualization of all saved time points. Providing a row of data points on the bottom of the large display and highlighting the current timestamp can be an option.

(a) (b) (c)

Figure 8.2: Snapshot Navigation: (a) Rotating from timestamp to timestamp. (b) Next timestamp. (c) Pushing the display for controlling the visualization.

8.1.2 Time Navigation

In contrast to the snapshot navigation, time navigation allows to view all artifacts produced during a specific time frame. The measured physical distance between two cubes indicates this time interval, which should be shown on a display (see Figure 8.3).

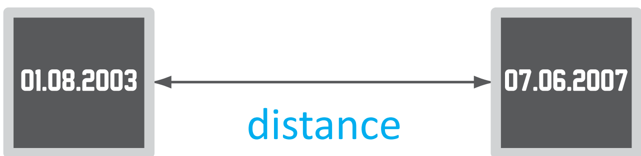
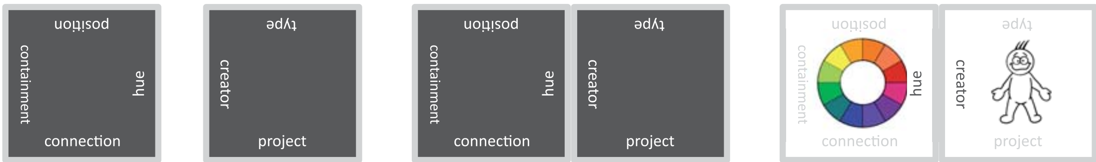


Figure 8.3: Physical distance indicates a time interval.

The main advantage in opposite to usual physical tokens is, that Sifteos work independently from the digital tabletop. In contrast to usual physical tokens, each cube's display could either show the start or the end date of the visualized artifacts. Important is to adapt the proportion between physical distance and time distance to the given data.

8.1.3 Attribute Mapping

One visualization is not always appropriate for all kind of tasks. Sifteos could give the user an appropriate tool for flexible attribute mapping. For example, the visual attributes *hue*, *position*,*containment* and *connection* can be mapped to *type*, *creator*, *project* (see Figure 8.4). If *hue* and *creator* are attached, one color will be assigned to each creator and artifacts will be highlighted in the corresponding color on the large display.



(a) (b) (c)

Figure 8.4: Snapshot Navigation: (a) Two cubes representing the attributes. (b) Mapping *hue* to *creator*. (c) Feedback to the user.

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Appendix A

Evaluation Documents

Appendix A includes the documents, which were handed to the participants during the user study. The documents are written in German.

- *Welcome text* was handed to the participants before the session started.
- *Consent form* was signed before the session began.
- *Pre-Test Questionnaire* was filled out in order to collect demographic data.
- *Study instruction* was given to the participant to instruct into the study procedure.
- *Introduction to the Blub interface (A)* described the visual representation and the guide of practice of all interaction techniques.
- *Introduction to the Bin interface (B)* described the visual representation and the guide of practice of all interaction techniques.
- *Questionnaires to the Blub interface (A)* consisting of AttrakDiff™ and SUS. AttrakDiff™ was handed to the user directly after the interaction session. The SUS was designed as directed questionnaire.
- *Questionnaires to the Bin interface (B)* consisting of AttrakDiff™ and SUS. AttrakDiff™ was handed to the user directly after the interaction session. The SUS was designed as directed questionnaire.
- *Interview manual* was used by the principal investigator in order to keep interviews consistent between participants. Participants were asked for a comparative rating of Blub and Bin interface in the end of the user study.
- *Confirmation of payment* was signed by participants after they received their funding.

Herzlich Willkommen !

Zunächst möchten wir uns bei Ihnen bedanken, dass Sie sich bereit erklärt haben, an unserer Untersuchung teilzunehmen. Bevor es nun gleich losgeht, wollen wir Ihnen mit Hilfe dieser kurzen Einführung vermitteln, um was es uns bei dieser Studie geht und welche Rolle Sie dabei spielen.

Ziel dieser Studie

Wie Sie möglicherweise bereits im Vorfeld erfahren haben, handelt es sich bei dem Gegenstand unserer Untersuchung, um die Evaluierung neuer Interaktionstechniken auf einem Multi-Touch-Gerät.

An dieser Stelle möchten wir ausdrücklich betonen, dass nicht SIE von uns geprüft werden, sondern Sie die Entwürfe der Benutzerschnittstelle für uns prüfen.

Für die Auswertung der gewonnenen Daten wäre es sehr hilfreich, wenn wir den Test auf Video und im Anschluss ein kurzes Interview auf Audio aufzeichnen könnten. Hierfür benötigen wir allerdings Ihr Einverständnis, wobei wir uns im Gegenzug verpflichten, das Videomaterial anonymisiert und lediglich zu Auswertungs- und internen Präsentationszwecken zu verwenden. In diesem Zusammenhang haben wir ein separates Dokument vorbereitet, das Sie auf der nächsten Seite vorfinden. Anschließend möchten wir Sie bitten, einen kurzen Fragebogen zu Ihrer Person (und zu ihrer Erfahrung mit Multi-Touch Geräten und der Bedienung dieser) auszufüllen.

Wir wünschen Ihnen viel Spaß und möchten uns noch einmal für Ihre Teilnahme bedanken!

Einverständniserklärung

Bitte lesen Sie die folgenden Zeilen aufmerksam durch.

Um eine bessere Auswertung der gewonnenen Daten zu ermöglichen, nehmen wir eine Videoaufzeichnung des Systemtests und im Anschluss eine Audioaufzeichnung eines kurzen Interviews vor. Durch die Unterzeichnung dieses Formulars erklären Sie sich damit einverstanden. Im Gegenzug verpflichten wir uns, die Aufzeichnung anonymisiert und lediglich zu Auswertungszwecken zu verwenden.

Des Weiteren möchten wir Sie bitten, bis zum Ende der Testreihe (Ende September 2011) über den genauen Ablauf der Untersuchung Stillschweigen zu bewahren, um andere potentielle Teilnehmer nicht zu beeinflussen.

An dieser Stelle möchten wir Sie auf Ihre Rechte während der Untersuchung hinweisen:

- Sie können den Test JEDERZEIT ohne negative Konsequenzen abbrechen.
- Sollten Sie eine Pause benötigen, teilen Sie uns dies bitte unverzüglich mit.
- Wenn Sie Fragen zum generellen Testablauf haben, können Sie diese jederzeit stellen. Bitte haben Sie jedoch Verständnis dafür, dass wir systemspezifische Fragen erst nach dem Test beantworten können, um eine Verfälschung der Daten zu verhindern.

Ich habe alle oben genannten Punkte gelesen und verstanden. Ich erkläre mich mit allen Punkten einverstanden:

Name, Vorname ____

Unterschrift des Teilnehmers ____

Datum ____

Die Untersuchungsleitung verpflichtet sich mit ihrer Unterschrift, die Videoaufzeichnung sowie sämtliche Daten dieser Untersuchung zu anonymisieren und lediglich zu Auswertungs- und internen Präsentationszwecken zu verwenden:

Name, Vorname ____

Unterschrift des Untersuchungsleiters ____

Datum ____

Fragebogen

Angaben zur Person

Alter: ________

Geschlecht:

☐ männlich ☐ weiblich

Ihr höchster Schulabschluss:

- ☐ Fachhochschulreife
- ☐ Hochschulreife
- ☐ Bachelor-Abschluss
- ☐ Master-, Magister-, Diplom-, Staatsexamens-Abschluss
- ☐ Sonstiges: ________________________________

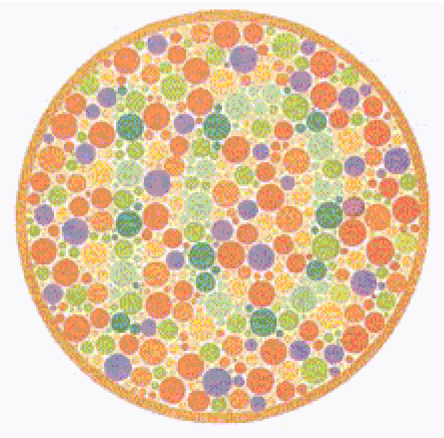
Sind Sie derzeitig …

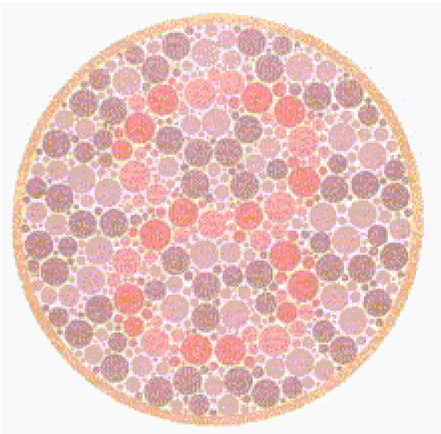
- ☐ berufstätig als ____________________________________
- ☐ in Ausbildung / Studium für __________________________
- ☐ arbeitssuchend
- ☐ Sonstiges: ________________________________

Sind Sie…?

- ☐ Linkshänder
- ☐ Rechtshänder
- ☐ beides
- ☐ weiß nicht

Welche Zahlen erkennen Sie in den Kreisen? Tragen Sie bitte die Zahl in den nebenstehenden Kasten ein.





☐ weiß nicht

Fragebogen

Angaben zur Erfahrung mit Multi-Touch Geräten

Wie viele Stunden verbringen Sie pro Tag an einem Computer?

- ☐ bis zu 1 Stunde
- ☐ mehr als 1, bis zu 2 Stunden
- ☐ mehr als 2, bis zu 3 Stunden
- ☐ mehr als 3 Stunden

Haben Sie bereits Erfahrung mit technischen Geräten, die durch berührungsempfindliche Displays bedient werden?

☐ ja ☐ nein

Falls ja, wie häufig nutzen Sie folgende Geräte?

	täglich	mehr als 1 mal in der Woche	mehr als 1 mal im Monat	weniger als 1 mal im Monat	jährlich
Deutsche Bahn Fahrkartenautomat oder ähnlicher Automat	☐	☐	☐	☐	☐
iPhone oder ähnliches Smartphone	☐	☐	☐	☐	☐
iPad oder ähnliches Tablet	☐	☐	☐	☐	☐
Multi-Touch Tisch (z.B. auf Messen)	☐	☐	☐	☐	☐
Sonstiges	☐	☐	☐	☐	☐

Gefällt Ihnen im Allgemeinen die Bedienung per Touch eher besser oder schlechter als andere Eingabe?

sehr viel besser ☐ ☐ ☐ ☐ ☐ **sehr viel schlechter**

Allgemeine Instruktionen

Ablauf

Die gesamte Studie umfasst zwei Abschnitte. Dabei werden Sie immer wieder dieselbe Aufgabe erledigen. Zu Beginn jedes Abschnitts erhalten Sie die Möglichkeit sich mit der Oberfläche und der Aufgabe vertraut zu machen. Versuchen Sie möglichst alle auf den nächsten Seiten dargestellten Interaktionsmöglichkeiten während dieser Phase auszuprobieren.

Ablauf
1. Abschnitt
2. Abschnitt

Aufgabe

Mithilfe der vorgegebenen Oberfläche werden Sie einzelne Rechtecke farblich gruppieren. Wurde zu jeder Farbe **eine** Gruppe gebildet, die **alle Rechtecke der Farbe** enthält, gilt die Aufgabe als gelöst. Danach werden die Farben der einzelnen Rechtecke vertauscht und die Rechtecke sind erneut farblich zu gruppieren. Danach erfolgt eine kurze Pause und die Aufgabe startet von neuem.

Die Zeit für die Lösung einer Teilaufgabe ist beschränkt. Sollten Sie dieses Zeitlimit überschreiten, gelangen Sie dennoch zur nächsten Teilaufgabe.

Aufgabenblock
Gruppierung
Neugruppierung
Pause

Dauer

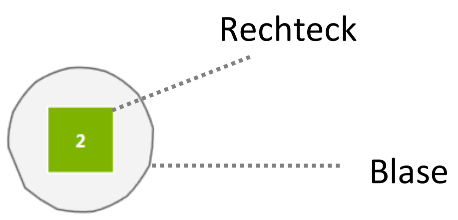
Die Gesamtdauer der Studie beträgt in etwa 60 Minuten.

A

Die Oberfläche

A) Visuelle Darstellung

Jedes Rechteck wird zu Beginn von einer Blase umgeben. Stellen Sie sich vor diese Blase ist eine Art Verpackung, die mit beliebigem Inhalt gefüllt werden kann und dabei ihre Form dem Inhalt anpasst.

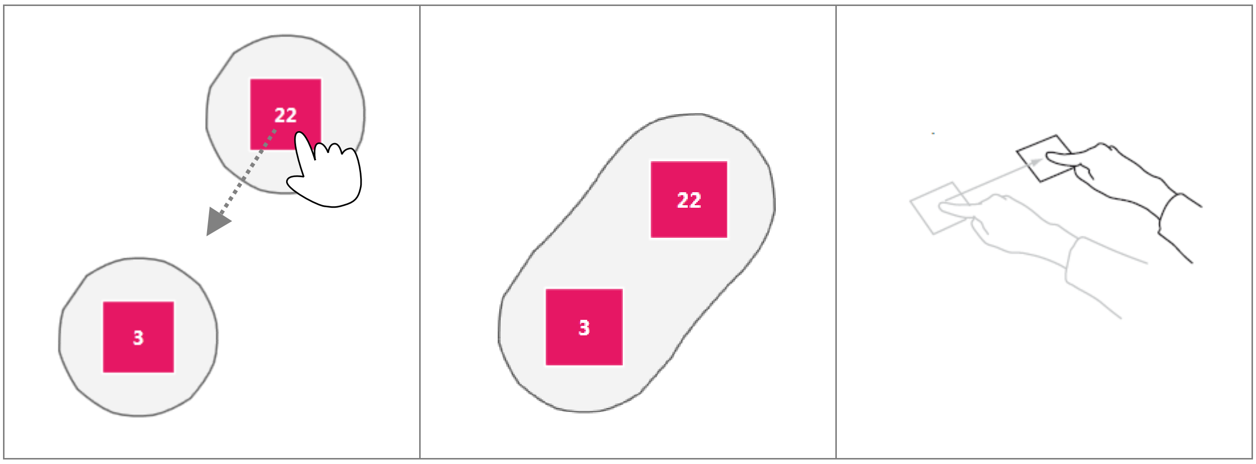


B) Verwendung der Oberfläche

Im Folgenden werden die einzelnen Interaktionen dargestellt. Versuchen Sie sich diese einzuprägen. Bevor die eigentliche Aufgabe beginnt, haben Sie die Möglichkeit die einzelnen Interaktionstechniken auszuprobieren.

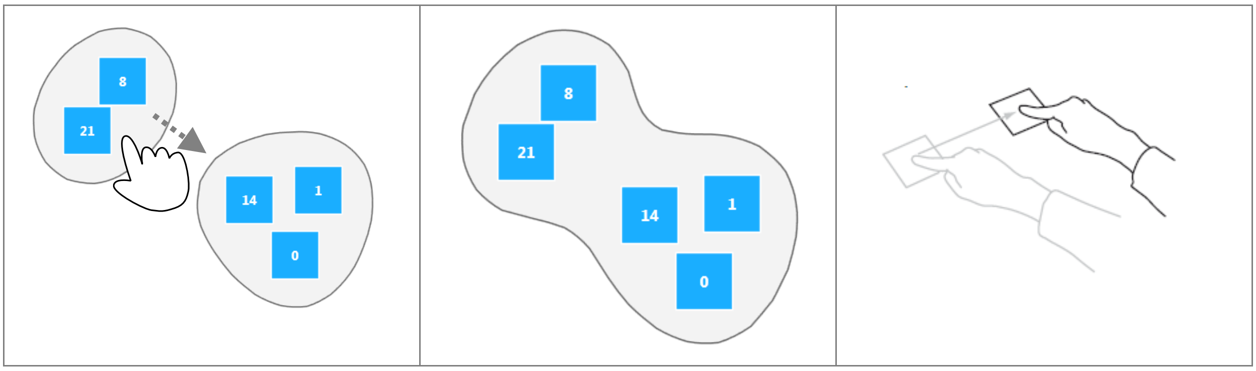
1. Gruppieren von einzelnen Rechtecken

Fassen Sie das Rechteck an und verschieben Sie dieses in die Nähe eines anderen Rechtecks.



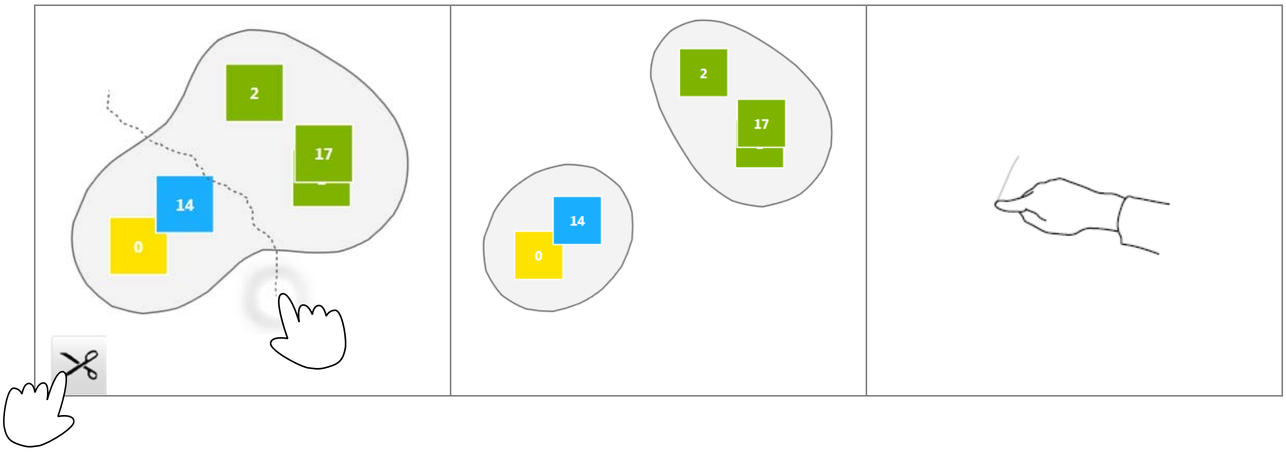
2. Gruppieren mehrerer Rechtecke

Um eine Blase mit einer anderen Blase zu verschmelzen, fassen Sie die Blase, verschieben Sie diese in die Nähe einer anderen Blase und lassen Sie los.



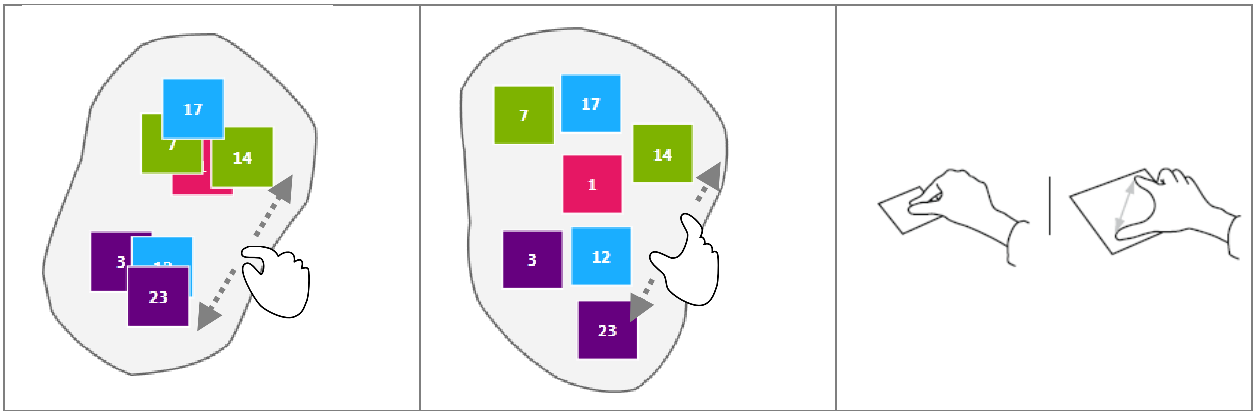
3. Teilen einer Blase

Halten Sie die Schere fest und ziehen Sie mit einem anderen Finger eine Linie durch die Blase.



4. Erweitern einer Blase

Ziehen Sie auf der Blase zwei Finger auseinander um einen Überblick über alle Rechtecke zu bekommen.

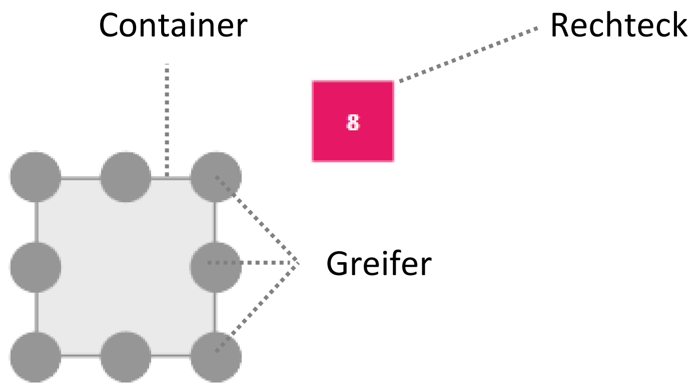


B

Die Oberfläche

A) Visuelle Darstellung

Stellen Sie sich vor, der Container ist eine Art Schachtel, die beliebig mit Inhalt gefüllt werden kann. Über die Form und Größe der Schachtel können Sie selbst entscheiden. Anders als im realen Leben werden die Rechtecke, die Sie in den Container stecken kleiner und Sie erhalten dadurch mehr Platz für neue Rechtecke.

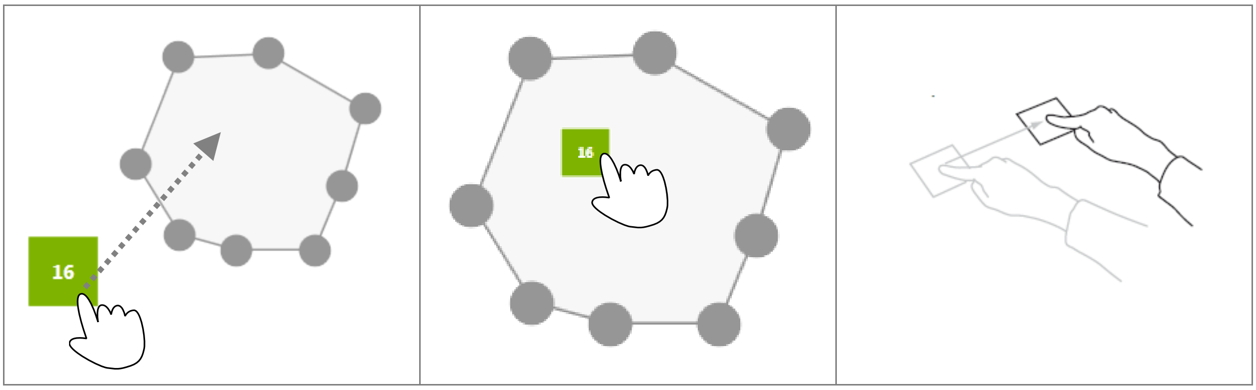


B) Verwendung der Oberfläche

Im Folgenden werden die einzelnen Interaktionen dargestellt. Versuchen Sie sich diese einzuprägen. Bevor die eigentliche Aufgabe beginnt, haben Sie die Möglichkeit die einzelnen Interaktionstechniken auszuprobieren.

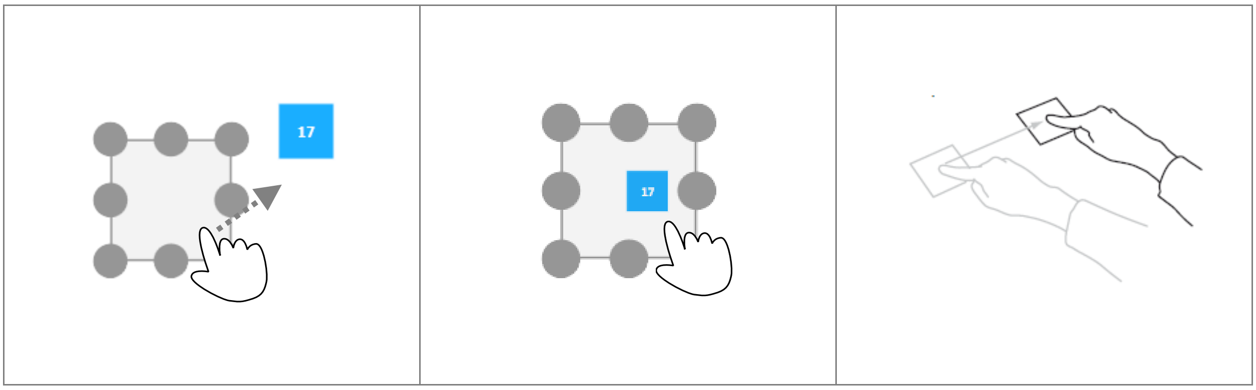
1. Einsammeln von einzelnen Rechtecken

Fassen Sie das Rechteck an und verschieben Sie dieses in einen Container.



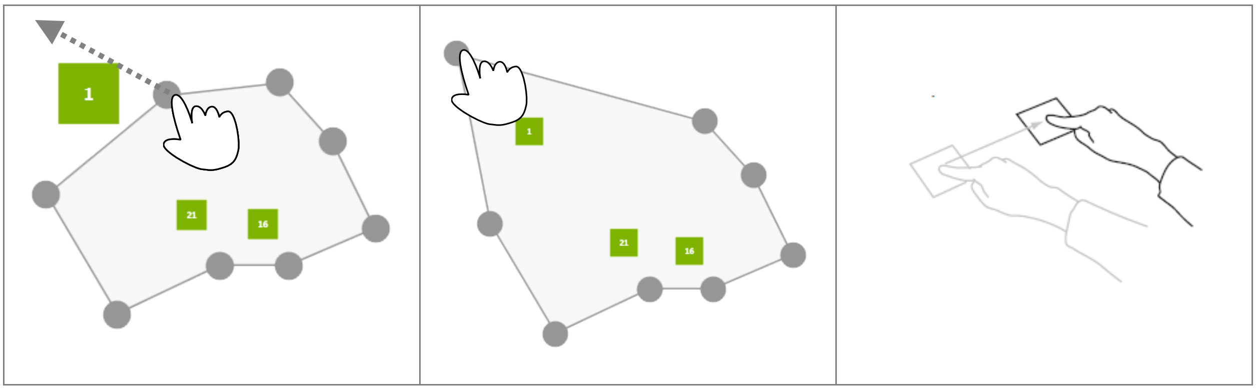
2. Aufsammeln von Rechtecken durch Verschieben eines Containers

Fassen Sie einen Container und lassen Sie diesen über dem gewünschten Objekt los.



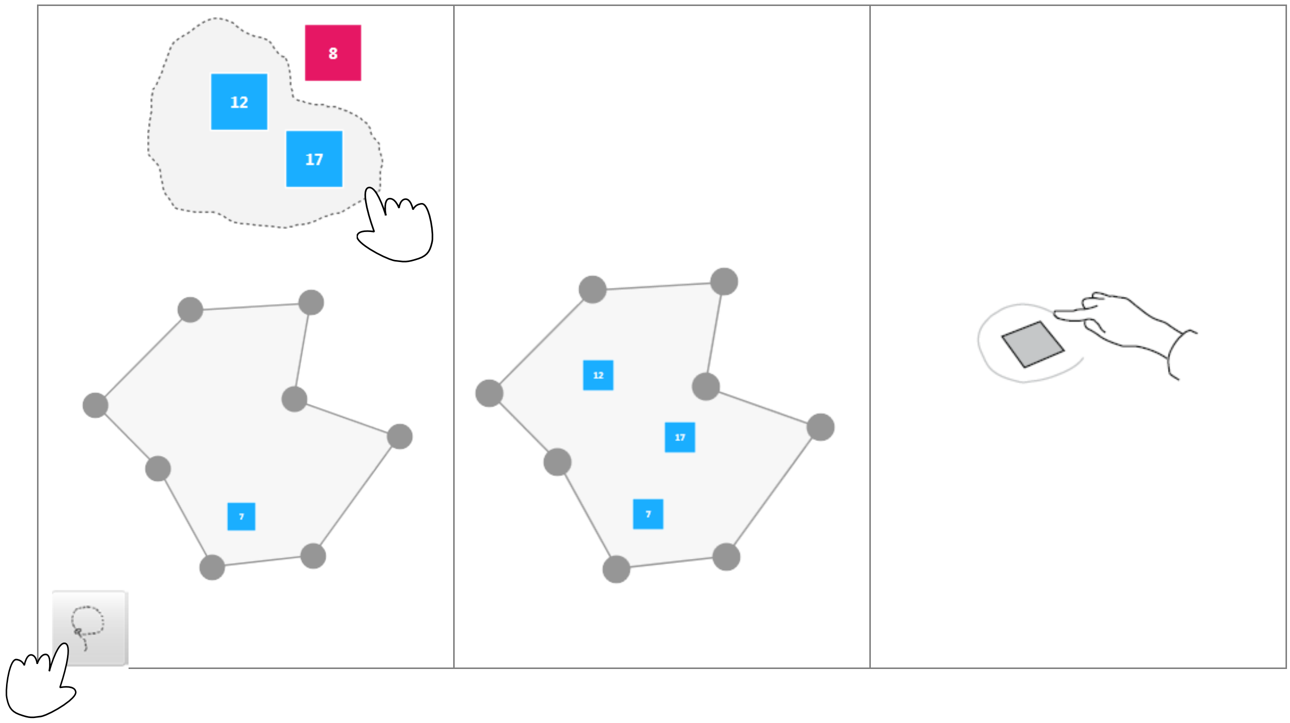
3. Aufsammeln von Rechtecken durch Verschieben der Greifer

Fassen Sie einen der Greifer, ziehen Sie bis der Container das gewünschte Rechteck umschließt und lassen Sie los.



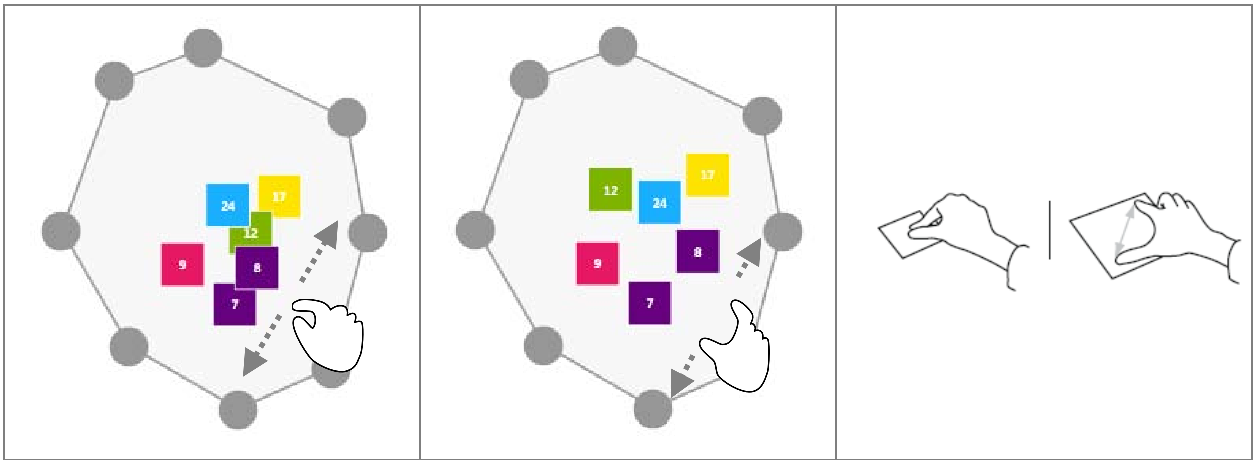
4. Aufsammeln von Rechtecken durch Lasso-Selektion

Halten Sie das Lasso fest und ziehen Sie eine beliebige Figur auf. Danach können Sie die selektierten Rechtecke an die gewünschte Position verschieben.



5. Erweitern eines Containers

Ziehen Sie auf dem Container zwei Finger auseinander um einen Überblick über alle Rechtecke zu bekommen.



Fragebogen

A	

Gesamteindruck

Bitte geben Sie mithilfe der untenstehenden Wortpaare ihren Gesamteindruck zu der benutzten Oberfläche wieder.

menschlich	☐	☐	☐	☐	☐	☐	☐	technisch
isolierend	☐	☐	☐	☐	☐	☐	☐	verbindend
angenehm	☐	☐	☐	☐	☐	☐	☐	unangenehm
originell	☐	☐	☐	☐	☐	☐	☐	konventionell
einfach	☐	☐	☐	☐	☐	☐	☐	kompliziert
fachmännisch	☐	☐	☐	☐	☐	☐	☐	laienhaft
hässlich	☐	☐	☐	☐	☐	☐	☐	schön
praktisch	☐	☐	☐	☐	☐	☐	☐	unpraktisch
sympathisch	☐	☐	☐	☐	☐	☐	☐	unsympathisch
umständlich	☐	☐	☐	☐	☐	☐	☐	direkt
stilvoll	☐	☐	☐	☐	☐	☐	☐	stillos
voraussagbar	☐	☐	☐	☐	☐	☐	☐	unberechenbar
minderwertig	☐	☐	☐	☐	☐	☐	☐	wertvoll
ausgrenzend	☐	☐	☐	☐	☐	☐	☐	einbeziehend
bringt mich den Leuten näher	☐	☐	☐	☐	☐	☐	☐	trennt mich von Leuten
nicht vorzeigbar	☐	☐	☐	☐	☐	☐	☐	vorzeigbar
zurückweisend	☐	☐	☐	☐	☐	☐	☐	einladend
phantasielos	☐	☐	☐	☐	☐	☐	☐	kreativ
gut	☐	☐	☐	☐	☐	☐	☐	schlecht
verwirrend	☐	☐	☐	☐	☐	☐	☐	übersichtlich
abstoßend	☐	☐	☐	☐	☐	☐	☐	anziehend
mutig	☐	☐	☐	☐	☐	☐	☐	vorsichtig
innovativ	☐	☐	☐	☐	☐	☐	☐	konservativ
lahm	☐	☐	☐	☐	☐	☐	☐	fesselnd
harmlos	☐	☐	☐	☐	☐	☐	☐	herausfordernd
motivierend	☐	☐	☐	☐	☐	☐	☐	entmutigend
neuartig	☐	☐	☐	☐	☐	☐	☐	herkömmlich
widerspenstig	☐	☐	☐	☐	☐	☐	☐	handhabbar

A

Fragebogen

Gesamteindruck

Bitte geben Sie an, inwiefern folgende Aussagen für Sie zutreffen.
(1 = stimme überhaupt nicht zu … 5 = stimme völlig zu)

1. Ich denke, dass ich dieses System gerne häufig nutzen würde.

   1 2 3 4 5

2. Ich fand das System unnötig komplex.

   1 2 3 4 5

3. Ich denke, das System war einfach zu benutzen.

   1 2 3 4 5

4. Ich denke, ich würde Hilfe eines Technikers benötigen, um das System benutzen zu können.

   1 2 3 4 5

5. Ich halte die verschiedenen Funktionen des Systems für gut integriert.

   1 2 3 4 5

B) Verwendung der Oberfläche

6. Ich halte das System für zu inkonsistent.

1	2	3	4	5

7. Ich kann mir vorstellen, dass die meisten Leute sehr schnell lernen würden, mit dem System umzugehen.

1	2	3	4	5

8. Ich fand das System sehr mühsam zu benutzen.

1	2	3	4	5

9. Ich fühlte mich bei der Nutzung des Systems sicher.

1	2	3	4	5

10. Ich musste viele Dinge lernen, bevor ich das System nutzen konnte.

1	2	3	4	5

Fragebogen

B	

Gesamteindruck

Bitte geben Sie mithilfe der untenstehenden Wortpaare ihren Gesamteindruck zu der benutzten Oberfläche wieder.

menschlich	☐	☐	☐	☐	☐	☐	☐	technisch
isolierend	☐	☐	☐	☐	☐	☐	☐	verbindend
angenehm	☐	☐	☐	☐	☐	☐	☐	unangenehm
originell	☐	☐	☐	☐	☐	☐	☐	konventionell
einfach	☐	☐	☐	☐	☐	☐	☐	kompliziert
fachmännisch	☐	☐	☐	☐	☐	☐	☐	laienhaft
hässlich	☐	☐	☐	☐	☐	☐	☐	schön
praktisch	☐	☐	☐	☐	☐	☐	☐	unpraktisch
sympathisch	☐	☐	☐	☐	☐	☐	☐	unsympathisch
umständlich	☐	☐	☐	☐	☐	☐	☐	direkt
stilvoll	☐	☐	☐	☐	☐	☐	☐	stillos
voraussagbar	☐	☐	☐	☐	☐	☐	☐	unberechenbar
minderwertig	☐	☐	☐	☐	☐	☐	☐	wertvoll
ausgrenzend	☐	☐	☐	☐	☐	☐	☐	einbeziehend
bringt mich den Leuten näher	☐	☐	☐	☐	☐	☐	☐	trennt mich von Leuten
nicht vorzeigbar	☐	☐	☐	☐	☐	☐	☐	vorzeigbar
zurückweisend	☐	☐	☐	☐	☐	☐	☐	einladend
phantasielos	☐	☐	☐	☐	☐	☐	☐	kreativ
gut	☐	☐	☐	☐	☐	☐	☐	schlecht
verwirrend	☐	☐	☐	☐	☐	☐	☐	übersichtlich
abstoßend	☐	☐	☐	☐	☐	☐	☐	anziehend
mutig	☐	☐	☐	☐	☐	☐	☐	vorsichtig
innovativ	☐	☐	☐	☐	☐	☐	☐	konservativ
lahm	☐	☐	☐	☐	☐	☐	☐	fesselnd
harmlos	☐	☐	☐	☐	☐	☐	☐	herausfordernd
motivierend	☐	☐	☐	☐	☐	☐	☐	entmutigend
neuartig	☐	☐	☐	☐	☐	☐	☐	herkömmlich
widerspenstig	☐	☐	☐	☐	☐	☐	☐	handhabbar

B

Fragebogen

Gesamteindruck

Bitte geben Sie an, inwiefern folgende Aussagen für Sie zutreffen.
(1 = stimme überhaupt nicht zu … 5 = stimme völlig zu)

1. Ich denke, dass ich dieses System gerne häufig nutzen würde. — 1 2 3 4 5

2. Ich fand das System unnötig komplex. — 1 2 3 4 5

3. Ich denke, das System war einfach zu benutzen. — 1 2 3 4 5

4. Ich denke, ich würde Hilfe eines Technikers benötigen, um das System benutzen zu können. — 1 2 3 4 5

5. Ich halte die verschiedenen Funktionen des Systems für gut integriert. — 1 2 3 4 5

B	

B) Verwendung der Oberfläche

6. Ich halte das System für zu inkonsistent.

1	2	3	4	5

7. Ich kann mir vorstellen, dass die meisten Leute sehr schnell lernen würden, mit dem System umzugehen.

1	2	3	4	5

8. Ich fand das System sehr mühsam zu benutzen.

1	2	3	4	5

9. Ich fühlte mich bei der Nutzung des Systems sicher.

1	2	3	4	5

10. Ich musste viele Dinge lernen, bevor ich das System nutzen konnte.

1	2	3	4	5

Interview-Leitfaden

<table>
<tr><th colspan="3">Forschungsfrage</th></tr>
<tr><td colspan="3">Welches Interaktionskonzept wird von den Usern für die Gruppierungs-Aufgabe bevorzugt?
Warum wird dieses bevorzugt?</td></tr>
<tr><th colspan="3">Leitfrage / Erzählaufforderung</th></tr>
<tr><td colspan="3">Können Sie mir erzählen, warum Sie gerade die Blase / den Container bevorzugen?</td></tr>
<tr><th>Inhaltliche Aspekte</th><th>Aufrechterhaltungsfragen</th><th>Nachfragen</th></tr>
<tr><td>Was hat Ihnen an der Blase / dem Container besonders gefallen / nicht gefallen?
Was würden Sie verbessern?
Was würden Sie sich für die Zukunft wünschen?
Wo würden Sie die Blase / den Container einsetzen?
Wie empfinden Sie die Erlernbarkeit der Oberfläche?
Welchen Zusammenhang sehen Sie zwischen der Blase / dem Container und der Verwendung von mehr als einen Finger?</td><td>Gibt es sonst noch was?
Und sonst? Und weiter?
Fallen Ihnen noch andere Dinge ein?</td><td>Warum gefallen Ihnen gerade diese Dinge (nicht)?
Warum denken Sie, dies könnte wichtig sein?
Haben Sie eine Idee wie man schneller mit der Oberfläche umzugehen lernt?</td></tr>
</table>

Quelle: nach Cornelia Helfferich 2005: Qualität qualitativer Daten, Wiesbaden

Welche der beiden Oberflächen würden Sie bevorzugen?

Blase ☐ Container ☐

Blase	Container
+	+
-	-

Blase	Container
Verbesserungsvorschläge	**Verbesserungsvorschläge**
Bimanuale Interaktion	**Bimanuale Interaktion**

Sonstiges

Empfangsbestätigung

Hiermit bestätige ich, dass ich für die Teilnahme an der Studie „Evaluierung neuer Interaktionstechniken auf Multi-Touch“ 10 EUR in Bar erhalten habe.

Name	Unterschrift	Datum

Appendix B

DVD Content

The DVD provides the thesis, images used in the thesis in *.eps format, all evaluation documents (see Appendix A), data recordings of the study, documents of the detailed data analysis and videos describing the interaction techniques of Blub and Bin, presenting the interaction strategies applied by the participants and the best trials of each interface.

Format: DVD

B.1 Thesis

Path: /Thesis

Master Thesis_Anita Höchtl.pdf . . . . Master Thesis

Path: /Thesis/images/EPS

*.eps . . . . all original eps images

Path: /Thesis/images/PNG

*.png . . . . all original png images

Path: /Thesis/images/JPG

*.jpg . . . . all original jpg images

B.2 Evaluation Documents

Path: /Evaluation Documents

1.pdf . . . . Welcome text
2.pdf . . . . Consent form

3.pdf	Pre-Test Questionnaire
4.pdf	Study instruction
5A.pdf	Introduction to the Blub interface
5B.pdf	Introduction to the Bin interface
6A.pdf	Questionnaires to the Blub interface
6B.pdf	Questionnaires to the Bin interface
7.pdf	Interview manual
8.pdf	Confirmation of payment

B.3 Data Recordings

Path: /Data Recordings/Logs

log-session_clean_detail.*	Logged Operations

Path: /Data Recordings/Videos/Blub

*.mp4	Blub session recordings from each participant

Path: /Data Recordings/Videos/Bin

*.mp4	Bin session recordings from each participant

Path: /Data Recordings/Interviews

*.AVI	Interview recordings from each participant

B.4 Data Analysis

Path: /Data Analysis

Task Completion Times.xlsx	Task completion times of each participant, detailed overview, high score
Operations.xlsx	Twelve interaction profiles per participant (2 interfaces x 3 runs x 2 phases), best/worst Blub/Bin profiles
Interaction Profiles_Blub.xlsx	Extracted interaction strategies with task completion times, overview
Interaction Profiles_Bin.xlsx	Extracted interaction strategies with task completion times, overview
Questionnaires.xlsx	Aggregated Data and Data Analysis: Pre-Test Questionnaire, AttrakDiff™, SUS

Interview.xlsx	User Comments, Preferences
Video Analysis.xlsx	Analysis concerning bi-manuality and multiple finger input per participant, detailed overview, description of gestures
AttrakDiff.pdf	AttrakDiff™ Evaluation Report[1]

B.5 Videos

Path: /Videos

Blub - Interaction Techniques -*.*	Description of Blub's interaction techniques
Bin - Interaction Techniques -*.*	Description of Bin's interaction techniques
Interacting with Blub*.*	Interaction strategies applied by using Blub
Interacting with Bin*.*	Interaction strategies applied by using Blub
Blub vs. Bin - Best Runs.*	Best Runs of Blub and Bin (grouping and regrouping phase)
Blub - Best Trials*.*	Three best trials in the Blub condition (either grouping or regrouping phase)
Bin - Best Trials*.*	Three best trials in the Bin condition (either grouping or regrouping phase)
Blub - Best Run*.*	Blub's best run (grouping and regrouping phase)
Bin - Best Run*.*	Bin's best run (grouping and regrouping phase)

[1] Automatically generated by http://www.attrakdiff.de .

Messbox zur Druckkontrolle

— Druckgröße kontrollieren! —

Breite = 100 mm
Höhe = 50 mm

— Diese Seite nach dem Druck entfernen! —