Exploring Reality-Based User Interfaces for Collaborative Information Seeking

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Abstract

Information seeking activities such as searching the web or browsing a media library are often considered to be solitary experiences. However, both theoretical and empirical research has demonstrated the importance of collaborative activities during the information seeking process. Students working together to complete assignments, friends looking for joint entertainment opportunities, family members planning a vacation, or colleagues conducting research for collaborative projects are only few examples of cooperative search. However, these activities are not sufficiently supported by today's information systems as they focus on individual users working with PCs.

Reality-based User Interfaces, with their increased emphasis on social, tangible, and surface computing, have the potential to enhance this aspect of information seeking. By blending characteristics of real-world interaction and social qualities with the advantages of virtual computer systems, these interfaces increase possibilities for collaboration. To date, this phenomenon has not been sufficiently explored. This thesis is an analytical investigation of the improvements and changes reality-based user interfaces can bring about in collaborative information seeking activities.

To explore these interfaces, a realistic scenario had to be devised in which they could be embedded. The Blended Library has therefore been developed as the context for this thesis. In this vision, novel concepts have been developed to support information seeking and collaborative processes inside the physical libraries of the future; the Blended Library thus represents an appropriate ecosystem for this thesis. Three design cases have been developed that provide insight into how collaboration in information seeking may be influenced by reality-based user interfaces. Subsequently, two experimental user studies were carried out to attain more profound insight into the behavior of people working collaboratively, based on the type of interface in use.

Zusammenfassung

Das Recherchieren im Internet oder das Durchstöbern einer Mediensammlung werden häufig als Aufgaben einer Informationssuche betrachtet, die von einer Person alleine ausgeführt werden. Jedoch gibt es eine Menge an theoretischer und empirischer Forschungsarbeit, welche gerade die Bedeutung von kollaborativen und sozialen Aktivitäten während Suchprozessen hervorhebt. Studenten, die für eine Hausarbeit zusammenarbeiten, Freunde, die gemeinsam Informationen über das Freizeitangebot suchen, Familien, die zusammen ihre Urlaubsreise planen oder Arbeitskollegen, die gemeinsam für ein Projekt recherchieren, stellen nur ein paar anschauliche Beispiele dar. Jedoch wird diese Form des gemeinsamen Recherchierens bisher von heutigen Informationssystemen nicht ausreichend unterstützt. In den meisten Fällen sind sie für einen individuellen Benutzer, der alleine an einem PC arbeitet, zugeschnitten.

Realitätsbasierte Benutzerschnittstellen versprechen durch ihre starke Ausrichtung auf Social-, Tangible- und Surface-Computing das Problem zu lösen. Durch das Verschmelzen von real-welt Charakteristika, einschließlich der sozialen Qualitäten mit den Vorteilen von digitalen Computer-Systemen, können sie die Möglichkeiten der Kollaboration nachhaltig verändern. Jedoch wurden die Konsequenzen dieser Veränderungen bis heute noch nicht ausreichend erforscht. Deshalb wird in dieser Arbeit untersucht, welche positiven aber auch negativen Auswirkungen der Einsatz von realitätsbasierten Benutzerschnittstellen bei kollaborativer Informationssuche hat.

Als Kontext dieser Arbeit wurde ein realistisches Szenario, die Blended Library, entwickelt. In dieser Vision der physischen Bibliothek der Zukunft wurden Konzepte geschaffen, welche die Informationssuche und kollaborative Prozesse unterstützen. Dadurch stellt die Blended Library ein passendes Ökosystem dar, um die Forschungsfragen dieser Arbeit zu ergründen.

Insgesamt wurden drei Design Cases entwickelt, die aufzeigen, wie kollaborative Aktivitäten der Informationssuche in Zukunft durch realitätsbasierte Benutzerschnittstellen verändert werden können. Weiterhin wurden zwei Experimente mit insgesamt 93 Personen durchgeführt, um ein tiefgehendes Verständnis über die Verhaltensunterschiede von Informationssuchenden in Gruppensituationen abhängig von der Art der Benutzerschnittstelle zu erlangen.

Publications

Parts of this Thesis were published in

Journal Articles

- Heilig, Mathias; Demarmels, Mischa; Huber, Stephan; Reiterer, Harald (2010): Blended Library - Neue Interaktionsformen für die Bibliothek der Zukunft. in: Oldenbourg Wissenschaftsverlag, i-com - Zeitschrift für interaktive und kooperative Medien, 01/2010, http://i-com-media.de, p. 46-57, May 2010.

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- Heilig, Mathias; Huber, Stephan; Gerken, Jens; Demarmels, Mischa; Allmendinger, Katrin; Reiterer, Harald (2011): Hidden Details of Negotiation: The Mechanics of Reality-Based Collaboration in Information Seeking. to appear in INTERACT 2011: Proceedings of 13th IFIP TC13 Conference on Human-Computer Interaction, acm In-Cooperation, SpringerLink, Sep 2011.

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Workshops, Poster and Demos

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List of Abbreviations

CSCW	Computer-Supported Cooperative Work
e.g.	for example
etc.	and so on
GUI	Graphical User Interface
HCI	Human-Computer Interaction
IR	Information Retrieval
IS	Information Seeking
LSA	Latent Semantic Analysis
PKM	Personal Knowledge Management
RBI	Reality-Based Interaction
TUI	Tangible User Interface
UI	User Interface
ZOIL	Zoomable Object -oriented Information Landscape

1 Introduction

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."

Sir William H. Bragg (Nobel Prize 1915, 1862-1942)

Contents

1.1 Motivation

Information seeking (IS) activities such as searching the web or browsing a media library are often considered to be solitary experiences. However, a great deal of theoretical and empirical work has revealed the importance of collaborative activities during IS processes. Morris & Teevan (2009) provide some obvious examples: students working together to complete assignments, friends looking for entertainment options for a night out, family members jointly planning a vacation trip, or colleagues conducting research on a shared project. Similarly, Kuhlthau (2004) defines IS as a constructive process in which social and collaborative activities are essential to advance the pursuit of knowledge.

Working collaboratively clearly enhances the quality of IS activities in many different aspects – for example, by increasing coverage of the relevant information space and by reducing unnecessary and redundant work. In addition, collaborative work raises confidence in the quality of findings due to the constructive development of strategies and answers in a group that might include people with varied abilities and past experiences.

In today's digital IS systems, collaborative search is not sufficiently supported. The limitations of standard desktop or terminal PCs are one underlying reason; controlled by mouse and keyboard, this hardware offers no appropriate mechanisms for collaborative work. To overcome this deficiency, several researchers (e.g. Amershi & Morris 2008, Morris et al. 2010) have proposed the use of multi-touch tabletops for co-located, collaborative IS. These researchers theorize that the horizontal form factor of a tabletop interface will democratize the interaction between multiple users through the possibility of simultaneous touch operations. Furthermore, these settings promise a more natural interaction between users in a way that will enhance the perception of other users' interactions, gestures, and posture during work and discussions. The concept of tangible user interfaces (TUIs) is also proposed as a tool to support collaborative activities (Hornecker 2002). With the possibility of parallel manipulation and physical affordance, these interfaces promise to further enhance co-located collaborative activities using digital information systems.

Explanatory models for these effects are often derived from cognitive science and psychology. For example, one theory currently gaining in popularity in HCI is the embodiment theory (Gibbs 2006), which indicates that our cognitive development is crucially influenced by our physical and social interactions with objects and living beings in our environment. In addition, the field of HCI has begun to construct its own explanatory models, including embodied interaction (Dourish 2001) and reality-based interaction (RBI, Jacob et al. 2007, 2008), that incorporate findings from cognitive science, the technical evolution with regard to multimodal interaction, and research into surface, tangible, and social computing. The aim of these models is to guide the interaction design of digital systems by putting more emphasis on interactions with the real, non-digital world, thus designing a more "reality-based" and more natural experience. Different input techniques enable multimodal interaction in order to take advantage of the physical capabilities of users. To improve the understanding of digital systems, UIs are based on the rules of the physical world. The everyday knowledge of users is also regarded as a resource in the design of simple and effective computer systems. For example, reality-based UIs respect the social skills of users to facilitate collaborative work. Therefore, we believe that reality-based UIs have the potential to enhance collaborative, co-located IS.

1.2 Research Focus and Goals

"What impact do reality-based user interfaces have on collaborative information seeking?"

To date, the influence of reality-based UIs on collaborative work, especially on IS, has not been explored in detail. The research question stated above lies at the core of this thesis, which presents four years of academic inquiry in the field of Human-Computer Interaction (HCI).

Reality-based User Interfaces: The thesis focuses on reality-based UIs; this phrase is used as an "umbrella term" that includes UIs based on the understandings of embodied cognition (Chapter 2.1 and 2.2). Interaction with such UIs takes place in the real world in a physical and social environment rather than being enclosed within a desktop computer. To narrow this broad field of UIs, this thesis primarily emphasizes interfaces that make use of *multi-touch tabletops* and/or *TUIs*. There are several reasons behind this narrowed research scope: First of all, these types of interfaces are typical representatives for reality-based UIs. In addition, they promise to leverage reality-based qualities, especially in co-located collaboration situations (Hornecker 2002) and have already demonstrated some promising results in other domains (e.g., collaborative design, Maher & Kim 2005).

Collaborative Information Seeking: Within the general focus on the domain of collaborative IS, the thesis concentrates on the explicit engagement of people sharing an information need in a collaborative search setting.

The thesis examines in detail a subset of IS scenarios and tasks. These scenarios involve *small groups* of between two and four collaborators, as this is a population typical of a group in collaborative IS situations (Chapter 3.2); for example, a group of students working together on a project, private consultations with an advisor, or a family deciding on their next holiday destination.

Additionally, this thesis focuses on *co-located* and *synchronous* work settings, in which the collaborators share the same physical workplace at the same time. These face-to-face settings offer strong real-world characteristics, such as instant feedback, multiple channel communication, shared local context, individual control, implicit cues, and spatiality of reference (Olson & Olson 2000) – all features necessary to explore the impact of reality-based interfaces.

1.3 Research Challenges

To generate an elaborate description of how reality-based UIs can be designed to support collaborative IS situations, several challenges must be addressed.

Challenge 1 – Design of Reality-Based Interfaces: The design of reality-based interfaces is a relatively new domain, made possible only by technologies emerged in the past few years. As a result, there are only a few systems available that follow reality-based approaches. Consequently, there is no common experience base for the design, and no common standards or guidelines such as those found in the graphical user interface (GUI) world; in addition, user expectations differ widely. Furthermore, with new input modalities and device dimensions, established development tools and environments are no longer adequate. RBIs are not only pieces of software, but also involve hardware and environmental artifacts; no longer trapped in a desktop PC, the interface breaks out into the real world.

Adding to the challenge, there is no understanding of how these types of interfaces can be embedded in established processes and courses of actions generated by users.

Challenge 2 – Design for Collaborative Environments: In addition to the challenges of designing reality-based UIs, it is very difficult to explore and design for complex, multifaceted characteristics of collaborative environments. Every group develops dynamically over time, establishing roles and strategies and cultivating behavior patterns and standards that can vastly differ from group to group (Chapter 2.3.4).

Challenge 3 – Evaluation of RBIs in Collaborative Environments: To observe and evaluate reality-based UIs, several issues must be considered that would not be factors for standard desktop PCs.

The simultaneous and multiple input from different users is difficult to capture. Standard techniques such as mouse-event logging or screen captures cannot be utilized. Furthermore, the interactions occur to a great extent in the real world; because users are able to move freely in the environment, the orientation and spatial conditions can change continuously.

As the thesis focuses on collaborative environments, measuring the interactions between users as well as assigning interactions to a specific user poses additional challenges.

1.4 Research Approach

As an initial exploration of the topic of the thesis, an intensive *literature review* was carried out in the first phase in order to understand the motivations and underlying theories behind reality-based UIs. It was also important to gather past research results focusing on IS in order to understand users and their needs. References from related research fields (such as social psychology and CSCW) supply further insights, particularly in regard to group collaboration.

In parallel to the literature review, a scenario called the Blended Library was developed, based on the insights of the RBI and IS literature and experience from a previous research project, MedioVis (Heilig et al. 2008). The Blended Library is a vision of the library of the future, in which library users are supported in their natural IS processes by reality-based UIs. In order to actualize and test the idea, a case study including a horizontal prototype was developed and qualitatively evaluated. The Blended Library thus serves as the *context of the thesis*. All design cases and evaluation studies emerged out of this vision.

To support in particular the collaborative aspects in the vision of the Blended Library, in the second phase of the PhD project, three *design cases* were developed: Facet-Browsing, ScatterTouch and Search-Tokens. These design cases were informed by the insights drawn from the literature review and the results from the qualitative user study of the Blended Library case study in the first phase of the research. These design cases were analyzed in detail and their sustainability regarding applications under real-world conditions was assessed.

In the third phase, two in-depth *user studies* on the Search-Tokens design case were conducted to explore unresolved research questions – e.g., how users change their behavior and adopt different roles depending on different UIs in collaborative IS. To this end, alternative UIs were developed to approach these issues under experimental conditions. Throughout this phase, appropriate evaluation methodologies had to be chosen and developed. Finally, the results of the user studies, the design cases, and the vision of the Blended Library were considered in view of the insights gathered over the four years of research work.

1.5 Contributions

The thesis contributes to a richer understanding of how group behavior changes and how this can be exploited when using RBIs in IS. Specifically, this work offers three main contributions:

1. Scenario for IS with RBIs: The Blended Library provides a conceptual foundation with regard to the development of RBIs on the basis of key concepts drawn from theories in cognitive science and IS. The Blended Library thus offers an appropriate environment for the research of this thesis and provides in addition ample scope for further research.

2. Design Cases for Collaborative IS with reality-based UIs: The thesis demonstrates a set of design cases examining how co-located collaborative IS can be supported by means of reality-based UIs. The prototypes developed to explore the overarching research question show a possible approach to the afore introduced design challenges of reality-based UIs in collaborative environments (Chapter 1.3).

3. In-depth Understanding of Impact of reality-based UIs on Collaborative IS: The thesis extends our understanding of collaborative work with reality-based UIs, especially for IS activities. Insights derived from the literature review are enhanced, in particular by two extensive user studies that analyzed collaboration practices in co-located collaborative IS settings.

Side-Contribution. Research Methods to Evaluate reality-based UIs in Collaborative Environments: An additional contribution evolved as side effect of evaluating RBIs in co-located collaborative environments. Due to the lack of research methodologies to evaluate co-located collaborative settings with reality-based interfaces, methods had to be developed and applied in order to be able to conduct the user studies. These methods include methodologies for gathering empirical data as well as for processing and interpreting this type of data.

These contributions are discussed and explored in greater detail in the following chapters.

1.6 Thesis Outline

Chapter 1 (p. 1), the present chapter, explains the motivation for the general themes of the thesis. Based on this foundation, the essential research topic is introduced, clarifying the objectives regarding collaborative IS in co-located environments by means of reality-based UIs. The methodological approach to attain these objectives is described and the main contributions of the dissertation project are identified. Finally, the structure of the thesis is presented.

Chapter 2 (p. 9) provides an overview of the theoretical foundation for the PhD project. It presents general models and theories and defines terminology based from HCI, cognitive science, CSCW and social psychology on an intensive literature review, and thus offers the basic information necessary for the thesis.

Chapter 3 (p. 41) highlights collaborative IS as the research domain of this thesis. At the beginning of this chapter, theoretical and empirical IS models are analyzed with respect to shared as well as contrasting characteristics, which presents a picture of IS as a multifaceted process. Thereafter, the focus is on collaborative activities, explaining their importance in IS processes; the chapter defines terminology, group configurations, and a design space to categorize systems that support collaborative IS. Finally, Chapter 3 discusses already existing reality-based research approaches that seek to support collaborative IS activities as related work relevant to this thesis.

Chapter 4 (p. 61) introduces the Blended Library, which serves as the research environment and context for the thesis. The Blended Library implements concepts for the library of the future based on the theoretical insights described in Chapter 2 and the application of emerging technologies. Furthermore, the chapter presents a case study that illustrates the essential ideas behind the Blended Library.

Chapter 5 (p. 84) spotlights three design cases – Facet-Browsing, ScatterTouch, and Search-Tokens – that have each been developed as reality-based UIs in support of different aspects of collaborative IS in order to address the research question of this thesis. The chapter outlines the conception and design decisions in detail and describes the applied principles of RBI as well as the essential trade-offs for each design case.

Chapter 6 (p. 115) describes two experimental user studies associated with this thesis that empirically supplement the research theme. The first user study examines the behavior of participant groups under three different interface conditions using a multi-touch tabletop to detect influences on behavior patterns and effects on collaborative work. The second and more extensive user study clarifies the effects of reality-based UIs and their specific characteristics on collaborative IS processes (in comparison to desktop PC-based UIs).

Chapter 7 (p. 143), the conclusion, contains a summary including a description of the contributions presented in the thesis.

2 Theoretical Foundation

"It is the theory that decides what can be observed"

Albert Einstein (Physicist, Nobel Prize 1921, 1879-1955)

Contents

The following chapter describes the theoretical background of this thesis. In the first section (Chapter 2.1), the foundations of cognitive science and its connection to HCI will be outlined. Cognitive science provides essential insights into users' mental processes and contexts, which can be utilized in HCI. After a short definition of the two research fields, their common origins and the resultant intersections will be highlighted. Subsequently, two theories (activity theory and embodied cognition) are selected for detailed examination. These theories paint a new picture of human behavior (and the behavior of users of interactive systems) that has a tremendous influence on HCI. The impact of these theories on HCI and especially on the topic of this thesis will be emphasized at the end of this section.

The next section (Chapter 2.2) focuses on embodied and reality-based interaction, introducing approaches that seek to connect concepts from cognitive science to HCI. The similarities and differences between three complementary approaches will be explored in detail. The term "reality-based" as used in the title of this thesis will be defined as an umbrella term describing the insights presented in this section.

As this thesis emphasizes collaboration, the last section (Chapter 2.3) introduces important concepts and insights from the research field of Computer-Supported Cooperative Work (CSCW). After briefly outlining the background of this field, a model will be introduced that defines some basic concepts of collaboration. Thereafter, influential theoretical models for group work and group tasks that are used in this thesis to classify design cases and related work will be described. Finally, important research from social psychology that has fundamental importance for the design of collaborative systems will be introduced.

2.1 Human-Computer Interaction and Cognitive Science

HCI and cognitive science are research fields that share common roots. Although they have developed in different directions over the years, they have also profited abundantly from each other. In this section, the influence of cognitive science on HCI research will be emphasized, especially the impact on the research topic of this thesis.

2.1.1 Definitions and Background

Human-Computer Interaction: Hewett et al. (1992) drew up an early definition of Human-Computer Interaction (HCI) that has been widely used in recent decades:

"Human-Computer Interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them." (Hewett et al. 1992)

Expanding on this definition, HCI does not exclusively describe a single user working on a desktop computer (Dix et al. 2004): The *human* component can be represented by a single user, a group of users working together, or an organized community consisting of thousands of users. Likewise, *computer* could represent any technology, ranging from embedded systems and mobile devices to desktop computers to large high-resolution devices. *Interaction* denotes any purposefully accomplished communication between humans and computers.

Many perspectives and skills are required to design UIs. For this reason, HCI research has developed into a truly interdisciplinary field. The theme that holds this mixture of disciplines together is "the application of knowledge to the common domain of user interface design" (Boring 2002).

Cognitive science: Cognitive scientists have very diverse perspectives on the exact nature of their research field: some researchers define cognitive science as the science of the mind; others, as the science of humans as information processors; still others, as a behavioral science or simply as cognitive psychology (Boring 2002). These varying perspectives are the result of the fragmentation of cognitive science into various sub-disciplines addressing different research questions and using different methods. Nonetheless, these sub-disciplines share the "human mind" as a unifying theme.

HCI was and still is substantially influenced by cognitive science (e.g., Card et al. 1983, Carroll & Olson 1987). Cognitive science is necessary to understand users and to provide a solid foundation for determining their cognitive processes: Rogers et al. (2011) describes cognitive science as "the human in HCI". Cognitive science allows HCI researchers to understand, predict, and explain why and how users of interactive systems perceive and process information, use knowledge, and make decisions.

2.1.2 Common Roots

The research field of human factors emerged in the 19th century as a consequence of the Industrial Revolution and the resulting quest to make machines easier to operate (Meister 1999). Human factors is a multi-disciplinary field that emphasizes human requirements in the design and engineering of products and work processes to optimize system performance and user well-being.

A driving force in the progress of human factors was World War II: the aim of producing more effective weapons transformed the study of interactions between humans and machines into a central research topic. A consequence of these efforts was the development and formalization of the basic principles of information processing.

The dominant mode of thought during these days was behaviorism, the idea that the behavior of humans and other animals could be analyzed by applying methods from the natural sciences. In the late 1950s, the so-called "cognitive revolution" took place (Gardner 1985), during which early cognitivists (e.g. Chomski, Miller, Minski) emancipated themselves from behaviorism. A new perspective emerged – cognitivism – that sought to describe and model human processes.

In the 1960s, researchers became interested in the interaction between humans and computers. In subsequent years, the widespread dissemination of computer technology and advanced ideas such as GUIs and pointing devices resulted in the development of HCI as a distinct research field. Although they share a common ancestor in human factors, HCI and cognitive science drifted apart: HCI remained a largely applied research field, while cognitive science emphasized theoretical concerns.

At first, HCI researchers utilized the stimulus-response learning theory in order to gain insight about users; however, behavioristic approaches turned out to be inappropriate for the applied problems HCI addressed. Later, researchers sought to apply ideas from cognitive science in HCI. For example, Card et al. (1983) developed a model of the human processor that has roots in the general information-processing paradigm, a theory from cognitive science. The model seeks to quantify human performance (e.g., tasks completed, decisions made, and time spent in effort) during an interaction with a particular UI.

In the following sections, two theories that have an influence on modern HCI research will be introduced: the activity theory and the embodiment theory. These theories complement one another and build a foundation for the research described in this thesis.

2.1.3 Activity Theory

The activity theory is an interdisciplinary approach to the complex phenomenon of the purposeful use of information technology by individuals and groups in social contexts based on cultural-historical psychology. The theory represents a conceptual framework for consideration of human activity; however, activity theory cannot be seen as finished or as a strongly "predictive" theory (Bertelsen & Bødker 2003). HCI researchers are able to use this framework as an analytical tool, although not as a guide for the design and evaluation of UIs. Because of the attention paid to the social context, this theory provides insights for the collaborative aspect of the research topic of this thesis in particular.

Origins: The origins of this approach go back to Soviet psychologists, who analyzed how collective culture affects individual and collective thinking. The pioneers of this approach, Leontiev Vygotsky (1896-1934) and his colleagues, sought to study cognitive development as a process of socialization, thus attempting to improve peasant life through communism. After the revolution of 1917, there was great demand for a theory that could explain the social nature of human beings. Before this time, psychological theories were aimed at understanding the mental capacities of individual humans. With the activity theory, a new perspective on the cultural and technical mediation of human activity was developed that addressed the prevailing perspective of isolated people. Figure 1 shows the initial framework (triangle of activity) of the activity theory developed by Vygotsky and his collegues.

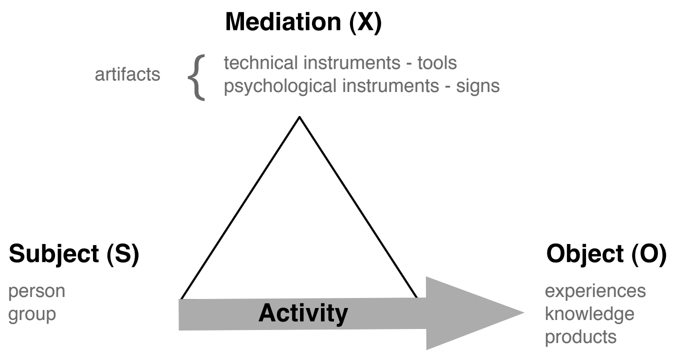


Figure 1 **Activity Theory (Vygotsky)**

In the definition of an activity from Vygotsky, one or more subjects (S) are able to reach an object/objective (O) via a mediation (X).

Aleksei Leontiev (1903-1979), a student of Vygotsky, refined this theory with regard to socially mediated activities (Figure 2). In addition to Vygotsky's individual mediation (X), Leontiev introduced the idea of mediation by a community (C). The community – also called the social context – is represented by people who share the same object or objective (O). The human subject (S) acts with or through other people in groups, communities, or organizations and is influenced by several social factors (e.g., culture or language).

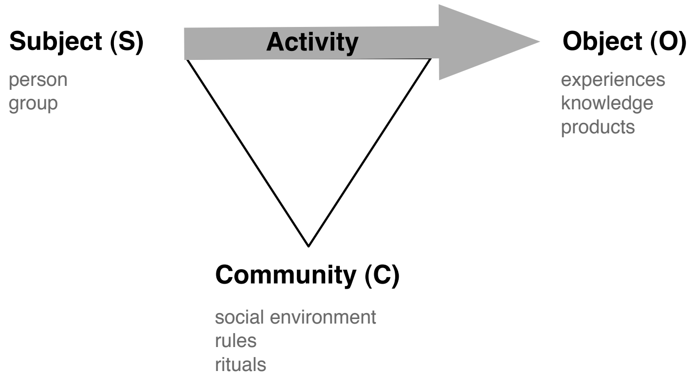


Figure 2 **Activity Theory (Leontiev)**

The community (C) is added as a social mediation to reach an objective (O).

In the late 1980s, Scandinavian researchers rediscovered the activity theory and reformulated it, calling this new version the Scandinavian activity theory. The leading researcher in this effort was Engeström, who re-structured the framework into an activity system or "web of activities" (Engeström 1987) to emphasize some aspects important to HCI that were only implicitly mentioned in the original model. In this new framework (Figure 3), "rules" have been introduced as relationships between the subject (S) and the community (C). These either explicit or implicit relationships define how a subject is positioned in the community or social context. An additional concept, "division of labor", describes the connection between the object/objectives (O) and the community (C).

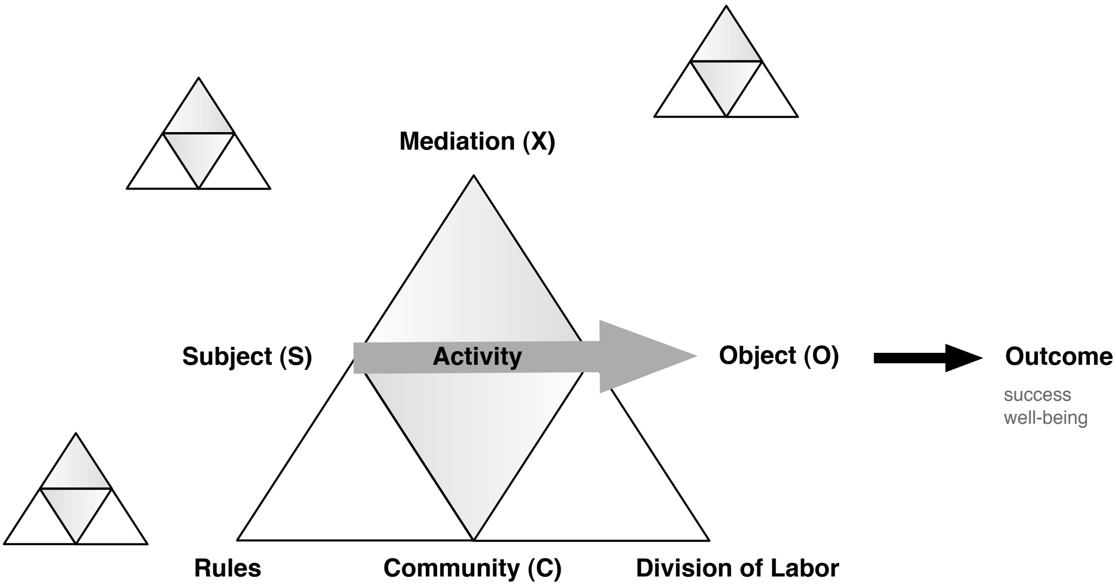


Figure 3 **Web of activities (Engeström 1987)**

Related elements of activity theory: The activity theory covers five related elements that define the framework in detail.

1. Object-Orientedness – In activity theory, the object or objective is described as the goal of the activity. Objectives give meaning to what people do and are not limited to physical artifacts. Typical examples for objects are “to acquire knowledge”, “to build something”, or “to give a talk”.

2. Hierarchical Structure – *Activity* is defined as a hierarchically organized system. Activities can be split into smaller units called *actions*. These goal-directed actions need to be consciously processed in order to achieve the object. Actions can be broken down again into *operations* that are executed unconsciously and habitually. These elements of activity are not fixed and may change dynamically as conditions change.

One example for this hierarchical structure is the activity “to give a talk” that consists of several actions, such as “to read a text”, “to prepare slides”, and “to search for appropriate examples”. An operation in this scenario could be “to maneuver the mouse”.

3. Internalization-Externalization – Activity theory assumes that there are transitions between mental (internal) and external representations. This is a result of human cognition, which cannot be divorced from the external actions of individuals. Internality and externality is also connected with the community or social context (Figure 4). Therefore, activity theory defines two separate dimensions of human activity: internal/external and individual/social.

	Individual	**Social**
Internal	image of the world internal plan of actions	attitude motivation
External	instrumental activity	communication collaboration

Figure 4 Two dimensions of human activity

Activity theory further specifies instruments used to alter these dimensions: *internalization* and *externalization*. By *internalization*, activity theory means the process of transforming conscious interactions with external objects into an unconscious plan of action, thus also changing the hierarchical structure. Internalization benefits from the human abilities to imagine, to consider alternative approaches, and to perform mental simulations. One typical example for internalization is the mathematical transition of children: in the beginning, they do number work with their fingers and hands (external), but after a while they learn to perform simple calculations in their heads without using their fingers (internal).

In contrast, *externalization* transforms an internal action into an external action. Unconscious and internalized behavior will be crystallized into a real-world action or artifact. This can be instigated for several reasons, such as changing conditions. One example is the execution of a calculation that would normally be completed mentally might be written out in full in a group situation so that the group members could follow each step.

4. Mediation – To achieve an object, activity is mediated by artifacts, also called instruments or tools. These artifacts are not necessarily represented externally (*external artifacts*); they can also be *internal artifacts*. *External* (physical) *artifacts* such as maps or diagrams assist in the mediation of external actions. These artifacts are often used in social situations to communicate with other individuals.

In contrast, the *internal artifacts* that occur in human minds are either natural psychological functions (e.g., imitation, results of practice, mental abilities, perception) or higher psychological functions (social experience) resulting from the processing of natural psychological functions in a cultural environment. These artifacts (e.g., language, numerical system) are utilized to enable people to interact with one another.

5. Development – Activity is described as a fluid state that continually changes as a consequence of contradictions and evolving requirements. This means, according to the web of activities (Engeström 1987) that one or more corner(s) change(s). To promote stability, activity theory proposes certain approaches, such as the development of the activity's hierarchy (e.g., automation of actions through internalization, or conceptualization through externalization).

Conclusion: In summary, activity theory illustrates a framework that can be used to describe interactions with information technology by individuals and groups in social contexts. People or users are thereby regarded as socio-culturally embedded actors. The context of and influences on these actors (subjects) can be analyzed with the web of activities. For the research topic of this thesis, in particular the community aspect and the mediation aspect with internal and external tools and their transitions will be taken into consideration.

2.1.4 Embodiment Theory

The second theory introduced in this section is the embodied view of cognition. This theory highlights the strong interconnection between human bodies and minds. According to embodiment theory, the human body creates an understanding of the world through direct perception.

HCI research makes frequent use of the insights of this theory and has developed important frameworks and approaches (Chapter 2.2) that are directly derived from it.

Origins: For a long time, the common view in cognitive science was that the human body and the mind should be regarded as two independent entities. This perspective is already represented in the Cartesian dualism that arose in the 17th century (Hart 1996). This concept assumes a strict separation of the physical world ("res extensa") and the mental space ("res cognita"). Even today, the idea of cognition as incorporeal and context-free signal processing influences the field of computer science and the design of interactive systems. A typical example of this can be found in Internet search engines, which offer a purely dialog-based and abstract interaction: Users enter search terms in a predefined logical language into an input field and the search engine provides results in a sorted list. The process of interaction exploits only the mental skills of the users; their physical and social skills as well as their prior real-world experiences are disregarded.

In the 20th century, a new perspective in cognitive science developed. This view envisions a tight coupling between perceptive thinking processes and actions, both physical and social. Gibbs (2006) termed this new perspective of human cognition "embodiment". An example of this close relationship between mental and physical actions is provided by Gibbs (2006), who conducted an experiment in which participants executed mental rotation tasks with virtual geometric shapes. During some of these tasks, the participants were asked to move their hands in the direction opposite to the mental rotation. Gibbs discovered that the performance of the participants strongly decreased during this hand movement.

Six views of embodied cognition (Wilson 2002): Wilson split the previously one-dimensional perspective of embodied cognition into six claims that frame the theory precisely.

1. Cognition is situated – Human cognition is always embedded in a real-world context and is thus regulated by perception and action.

2. Cognition is time-pressured – Cognition is strongly constrained by the requirement to work "under the pressures of real-time interaction with the environment" (Wilson 2002).

3. We off-load cognitive work onto the environment – Because of limited information-processing capacities, humans use the environment to reduce workload. Thereby, we "outsource" information or even information-processing tasks into the environment and gather only the relevant information units.

4. The environment is part of the cognitive system – As a result of the close connection and intercommunication between the mental and the external world, the environment and the context must be taken into account when analyzing cognitive processes.

5. Cognition is for action – The main intention behind cognitive processes is to control actions. From this perspective, cognition can be seen as "contribution to situation-appropriate behavior" (Wilson 2002).

6. Off-line cognition is body-based – Mental processes always depend on experiences that have developed through interaction with the environment (e.g., mechanisms of sensory processing or motor control). This is also true for someone who is not situated in the corresponding environment.

Conclusion: In summary, the embodiment view of cognition reveals the strong connection between the human mind and body. As Wilson (2002) states, "There is [in cognitive science] a growing commitment to the idea that the mind must be understood in the context of its relationship to a physical body that interacts with the world." This perspective stands in opposition to other theories of cognition, including cognitivism.

2.1.5 Impact

The theories discussed have already had a remarkable impact on HCI research. Activity theory, for example, allows descriptions of computer artifacts as part of a web of activity; in this way, they are considered in a real context and not in isolation. Computers are thus seen as tools that mediate daily activities, whether in relationship to things or to human beings.

Consequentially, Bødker & Andersen (2005) introduced three levels of mediation in computer-mediated work to analyze and understand human activities and their interplay with interactive systems: (1) physical aspects, or operations concerning interactive systems as physical objects (e.g., movement of pointing devices, pushing mouse or keyboard buttons); (2) handling aspects, or operations concerning interactive systems as virtual objects (e.g., moving graphical objects, zooming and panning); and (3) subject/object-directed aspects, or operations concerning objects or subjects inside the interactive system (e.g., sorting or structuring information).

In addition, Nielsen & Søndergaard (2000) described a "web of technologies" complementary to the "web of activities". This HCI-related addition to activity theory addresses the fact that people frequently switch between many computer applications, often applications running on different devices (e.g., desktop PCs, tablets, smart phones). The web of technology in combination with the web of activities permits HCI researchers to focus on contradictory demands and needs. Furthermore, these contradictions are seen as important driving forces of change and as opportunities to develop new and innovative concepts.

As a complement to the activity theory, the embodiment theory has also had a tremendous influence on HCI, especially over the past decade. The embodiment theory expounds that human skills and experience are directly connected with the world as a part of physical and social reality.

The logical consequence for the design of interactive systems is the holistic consideration of users, including their physical and cognitive skills as well as their context, social environment, and experiences. As a reaction, the field of HCI has begun to build its own explanatory models, summarizing findings from cognitive science and technical evolution with regard to multimodal interaction as well as surface, tangible, and social computing (Chapter 2.2). These models will be described in detail in the next section, as they build the foundation for the reality-based UIs that are the focus of investigation in this thesis.

2.2 Embodied and Reality-Based Interaction

Over the past decade, the focus of UIs has been shifting away from the desktop into new domains. This observation is the result of a continuously expanding design space that includes new physical forms and capabilities of computer devices, new interaction styles, combinations of devices, and the incorporation of context.

One of the pioneers in describing this shift was Weiser (1999) with his vision of ubiquitous computing. Weiser presented the idea that computational artifacts and interfaces move into the environment so that technology becomes invisible to people. Although his vision was very technology-driven, he was still aware of human capabilities: "Humans speak, gesture and use writing utensils to communicate with other humans and alter physical artifacts. These natural actions can and should be used as explicit or implicit input to ubicomp systems" (Weiser 1999). In complement to Weiser, Streitz et al. (2000) emphasized the environmental aspect of UIs: "The real world around us should be the starting point for designing the human computer interaction of the future."

Many of the emerging trends in HCI focus on the "connections between physical activity and cognition, and the intimately embedded relationship between people and other entities and objects in the physical world" (Dourish 2001). With this embodied cognition perspective (Chapter 2.1.4) in mind, a number of HCI researchers have developed approaches to connect this outlook to HCI.

In this section, three influential approaches will be presented: embodied interaction (Dourish 2001), how bodies matter (Klemmer et al. 2006), and RBI (Jacob et al. 2007, 2008). These approaches each have a different emphasis and thus complement each other.

2.2.1 Embodied Interaction

Paul Dourish, with his approach of "embodied interaction" (Dourish 2001), was the first HCI researcher to intentionally map the insights of embodiment to HCI. In his perspective, embodied interaction focuses on the "interaction with computer systems that occupy our world, a world of physical and social reality, and that exploit this fact in how they interact with us." He bases his approach partly on the phenomenology research of philosophers such as Heidegger, Husserl, and Merleau-Ponty, but also addresses two emerging trends in HCI research – namely, tangible computing and social computing. The phenomenological view of embodiment used in his approach is not strictly restricted to experiences of the physical body. Dourish (2001) states that embodied phenomena occurring in real time and space make interaction with the world meaningful. He points out that embodiment concerns how actions create meaningful events, and how others understand those actions as meaningful; this covers far more than what people do. Based on this argumentation, Dourish (2001) defines embodied interaction as "the construction of shared meanings through interaction with artifacts". Thus, embodied interaction is not intended to describe interaction; rather, it is conceived as an analytical framework for HCI that takes embodiment as a complete phenomenon into consideration.

Two emerging trends – tangible and social computing: In addition to the phenomenological embodiment perspective, Dourish (2001) considers two trends from the research field of HCI that were evolving at the time he was writing his book: tangible and social computing. He states that these new types of interfaces enable an "expansion of the range of human skills and abilities that can be incorporated into interaction with computers" – in his perspective, embodiment is central to these alternative perspectives of interaction.

Tangible computing – With the advent of graspable interfaces (Fitzmaurice 1996) or TUIs (Ishii & Ullmer 1997) at the end of the 20th century, a new research field emerged that created projects including the Marble Answering Machine (Bishop 1992), the Digital Desk (Wellner 1993), Tangible Bits (Ishii & Ullmer 1997), and URP (Underkoffler & Ishii 1999). Dourish (2001) sees this form of interaction as an important way to integrate computation into the physical world. Tangible computing offers a wide variety of physical interactions that fit into his approach, e.g., by integration of physical mapping and exploitation of physical affordance and distributed (rather than sequential) interaction. Furthermore, he emphasizes that the augmentation of the real world with computational power transforms dead objects into "active entities that respond to their environment and people's activities". This allows people to interact with computational devices through physical artifacts.

Social computing – Similarly, Dourish (2001, who has a strong research background in the field of CSCW) considers social computing as an attempt to transfer sociological understandings of the world into interactive systems. He argues that looking beyond the traditional single-user workplace, the involvement of other people and their activities could enhance HCI. He therefore proposes the application of anthropological and social ideas to facilitate the "mechanism through which people organize activity, and the role that social and organizational settings play in this process".

Meaning and coupling: Fundamental features of Dourish's embodied interaction (2001) are "meaning" and "coupling". From his point of view, embodiment and the associated phenomenology consist of the close coupling of action and meaning.

Meaning – In his approach to embodied interaction, meaning arises through interaction. From this perspective, technology and computing devices have no meaning until someone interacts with them.

Dourish (2001) further identifies three aspects of meaning: ontology, intersubjectivity, and intentionality. Onthology concerns people's conceptual model of the world developed from perceived and (through interaction) experienced entities (e.g., computational artifacts) and relationships. Intersubjectivity is concerned with how meaning can be shared with others. Thereby, this aspect can be split up into the communication of meaning from designer to user and the communication among users throughout a system. The third aspect, intentionality, describes the intention behind an action and thus the directedness of meaning.

Coupling – While actions generate meanings of entities for people, coupling is described as a tool to create relationships between entities. Only if this coupling has been established, actions can be executed by people through the entity. Dourish (2001) explains this concept using the example of a hammer (originally proposed by Heidegger): If a person uses a hammer to hit a nail, the hammer can be seen as an extension of the person's arm. Hence, the hammer is coupled and the person is able to engage in the activity of hammering by acting through the hammer onto the nail. This concept demonstrates parallels to the mediated activity concept introduced in the discussion of activity theory (Chapter 2.1.3).

Design principles of embodied interaction: Based on the foundations described and his view of interaction as "not just how we act on technology, but how we act through it" (Dourish 2001), Dourish developed six high-level design principles for HCI researchers to study how people interact with technology:

- Computation is a medium
- Meaning arises on multiple levels
- Users, not designers, create and communicate meaning
- Users, not designers, manage coupling
- Embodied technologies participate in the world they represent

- Embodied interaction turns action into meaning

These principles should not be seen as constituting a strict framework. Rather, they are meant to "observe or comment upon general features of embodied interaction that occur across a range of settings" (Dourish 2001).

Conclusion: In his embodied interaction approach, Dourish (2001) seeks to explain how people use computational artifacts in their activities and how these affect decisions. The concept that only an interaction with an artifact creates meaning is a perspective that will be considered in this thesis. The idea of people "interacting through" instead of "interacting with" a computational artifact as a medium draws strong parallels to activity theory.

From an embodied interaction point of view, it is essential for the design of interactive systems to understand that it is not the designer but rather the users themselves who create and communicate meaning by interacting with the system. However, as the approach of embodied interaction is quite theoretical and abstract, there are very few cases showing how these design principles have been applied in practice.

2.2.2 How Bodies Matter: Five Themes for Interaction Design

Six years after Dourish (2001) introduced his embodied interaction, Klemmer et al. (2006) published their work "How Bodies Matter: Five Themes for Interaction Design". They also apply concepts from embodied cognition theory to HCI, attempting to generalize the results from tangible interface research. In contrast to Dourish (2001), they do not insist on the phenomenological perspective of embodiment.

The impetus for their work was the observation that current desktop settings are used as a general tool for each type of task (e.g., word processing, web browsing, personal information management), operating with the same general modality: mouse and keyboard. The authors believe that by breaking this "homogenized" situation, interaction can be realized in a better way. To accomplish this, Klemmer et al. (2006) defined five themes for designing interactions.

Thinking through doing: The first theme "thinking through doing" emphasizes the fundamental insight of embodied cognition that the body and the mind are deeply integrated.

One aspect of this idea is that *learning through doing* is the way we learn everything (e.g., how to walk as a child, or our general understanding of the environment). This means that people's physical interactions in the world enable cognitive development. This knowledge can be valuable in designing interactions. For example, studies have shown that TUIs have a positive influence on the understanding of mathematical concepts in elementary school pupils.

Another aspect of this theme is *the role of gesture*. Gesture is an essential instrument from a very early age (as pre-linguistic communication) up to adulthood (as a conceptual planning tool for speech production). It helps people to communicate ideas that are not easily verbalized and thus facilitates the cognitive load. Therefore, Klemmer et al. (2006) argue that interactions that constrain our gestural abilities are likely to hinder our thinking and communications.

Similar to Dourish (2001), the authors mention that by manipulating an artifact, people develop a better understanding. As examples, they show how players of games like Tetris or Scrabble manipulate pieces of the game to understand how different options would work. These *epistemic actions* are valuable tools for exploiting the environment and thus lightening cognitive load.

This aspect is very close to the approach of "working it through, rather than just thinking it through". Thereby, Klemmer et al. (2006) argue for the epistemic creation of concrete prototypes to reflect ideas. This *thinking through prototyping* promises to lead to unexpected perspectives and creative surprises that would not be attained without prototyping.

The final aspect described for this theme is concerned with the *representation* of a problem in the world that essentially affects understanding. The authors argue that if a problem is represented in the right way (e.g., using realistic terms and real-world examples rather than subjective or vague descriptions), this often allows people to clearly see the most relevant constraints, thus rendering the solution more obvious. This concept is very similar to the concept of externalization in activity theory (Chapter 2.1.3). Implementing TUIs may offer familiar mappings and a variety of real-world metaphors to provide representations that facilitate interaction. However, the authors caution that "some mappings between the physical and the virtual [world] work, while others do not". Therefore, Klemmer et al. (2006) recommend that system designers look precisely at the representation through which people will interact with a system, as this contributes to task transparency.

Performance: This theme concentrates on the various modalities and human body skills that are capable of interaction. In parallel to Dourish's approach (2001), the authors also refer to acting through an (computational) artifact instead of acting with it (Chapter 2.2.1).

As a first input modality, they focus on *hands*, which are endowed with two essential body functions: complex expression and sensation. For the most tangible actions, these functions are linked, e.g., applying force and sensing pressure while grasping an object. Furthermore, Klemmer et al. (2006) also declare that the most powerful way to use human skills would be if people perceived an artifact to be an extension of their bodies, similar to Dourish's (2001) concept of coupling (Chapter 2.2.1). Through daily use of their hands to operate their tools, some professionals (such as surgeons and musicians) have advanced this interaction nearly to perfection. To date, such rich interactions have seldom been exploited in HCI.

Using *motor memory* (or kinesthetic memory), people are able "to sense, store and recall their muscular effort, body position and movement to build skill" (e.g., to ride a bike or to play the piano). Klemmer et al. (2006) argue that by addressing various functions of a UI through appropriate bodily actions (e.g., physical feedback), users may be better equipped to take advantage of their motor memory.

A final aspect mentioned under the theme of performance is that *reflective reasoning is too slow*. The authors state that many daily activities such as driving a car "require complex yet rapidly bodily responses for which planning through explicit cognition is simply too slow". These responses are called "learned skillful behaviors" or "experiential cognition" and stand in opposition to reflective cognition. In interaction design, these skills could be effectively implemented to facilitate body-centric experiential cognition, as the success of rich physical input devices such as game controllers suggests.

Visibility: Klemmer et al. (2006) state that "visibility" is especially important when using computational artifacts in a social context – for example, when people learn skills by watching someone else performing a task or by participating in a community of practice (*situated learning*). From Dourish's embodied interaction (2001) perspective, this would be a typical example of communicating the meaning of artifacts. However, modern computational artifacts do not allow such peripheral participation when people are using standard GUIs operated by a keyboard and mouse.

In addition, Klemmer et al. (2006) argue that "the production and manipulation of visible artifacts in the workplace *facilitate coordination*". The values of these physical acts of handling are important, especially in supporting synchronous collaboration. These properties are very difficult to translate into the digital world.

Furthermore, people place great value on the visibility of creative production or artistic *performances*. This is the reason why people go to concerts while they could listen to the same music at home on recordings.

Risk: The fourth of the five themes explores how uncertainty and risk impact interactions with computational artifacts.

Kelmmer et al. argue that *physical action is characterized by risk*, because the results of actions in the real world cannot be undone. Hence, people have to decide on an option "while the consequences of the action are not fully knowable ahead of time". Because of their awareness of corporal vulnerability, people are constantly prepared for danger and surprises. Like a physical action, an incorrect behavior in social interaction also cannot be undone. Therefore, interactions in the real world require more *commitment* and *trust* to execute an action. In contrast, computer systems offer mechanisms to minimize this risk (e.g., with undo or redo functionalities). In the perspective of Klemmer et al. (2006), this is the most distinctive difference between digital and real interactions.

However, risk is not always a negative characteristic: For example, in group work, the existence of risk can lead to more committed involvement by participants. Furthermore, if more risk is involved in a task, people "tend to have a bigger sense of *personal responsibility*" for their actions. This seems to be a consequence of the fact that actions are directly visible to other group members. Therefore, Klemmer et al. (2006) come to the conclusion that "making the implications of one's actions more visible (making risk more salient) increases one's sense of personal responsibility for decisions, helping to overcome the human inclination to authority".

Another property influenced by risk is *attention* during the interaction. It seems that higher risk results in people being more focused and paying more attention to detail. In contrast, if the risk is lower, people feel more relaxed and tend to work in a more creative manner. The authors thus come to the conclusion that risk, attention, and engagement are closely connected and should be regarded purposefully in the design of interactive systems.

Thick practice: The last theme of Klemmer et al. (2006) focuses on the ambivalence of translating physical actions into digital actions and *vice versa*. New technologies might offer previously unavailable functionality or the ability to execute actions more reliably and accurately. This often leads to digital replacements for physical actions. Although these intangible solutions have advantages, interaction designers should take great care not to unreflectively replace physical actions. As explained in the themes above, the physical world has many properties from which computational artifacts could benefit. The authors arrive at the conclusion that "solutions that carefully integrate the physical and digital world – leaving the physical world alone to the extent possible – are likely to be more successful by admitting the improvisations of practice that the physical world offers".

Conclusion: The five themes of Klemmer et al. (2006) point out how important embodiment and tangible interactions are throughout our lives. In contrast to Dourish (2001), Klemmer et al. (2006) focus in a more practical manner on the characteristics of interaction that arise from the perspective of embodied cognition. Although there are some parallels to Dourish's (2001) approach and also connections to activity theory, the authors complement these with valuable new insights to construct a bridge between embodied cognition and HCI. In particular, the themes "visibility" and "risk" open up new perspectives for designing interfaces for co-located collaboration that will be taken into consideration for this thesis.

2.2.3 Reality-Based Interaction

Just one year after the publication of the work by Klemmer et al. (2006), Jacob et al. (2007) presented their framework of RBI, another approach that seeks to connect the ideas of embodied cognition with HCI (Jacob et al. 2007, 2008). RBI is intended to be a unifying concept that ties together, compares, and relates a large subset of emerging interaction styles. The framework should thereby help interaction designers to take advantage of users' internalized skills, pre-existing knowledge, and expectations about the real world. Prior generations of HCI researchers defined common characteristics and a theoretical framework for the desktop metaphor (Hutchins et al. 1985); Jacob et al. (2008) seek to provide a similar structure for the new generation of UIs. They propose that "this new generation is unified by an increased use of real-world interactions over previous generations".

The authors define two overlapping classes of RBI: interaction *in the real world* and interaction *like the real world*. The first class focuses on computational artifacts that break out of the borders of the desktop into the world. The second is concerned with the transfer of knowledge from the real world into the virtual world.

Themes of reality: Jacob et al. (2008) identify four themes of reality that play a prominent role in emerging interaction styles. These themes are very closely connected to the concepts of embodiment and include people's understanding of naïve physics, their own bodies, the surrounding environment, and other people. According to Jacob et al. (2008), these themes can be applied almost universally to all people and cultures.

Naïve physics (NP) – Already at a very early age, children gather common-sense knowledge about their surrounding physical environment. Naïve physics (e.g., knowledge of gravity, friction, velocity, persistence of objects, relative scale) is included in this knowledge, as it represents basic principles of human perception. The authors point out that TUIs promise to address this theme (e.g., by employing physical constraints).

Body awareness and skills (BAS) – Beyond the common-sense knowledge of naïve physics, people develop an awareness of their physical bodies (e.g., relative position of limbs, range of motion, senses) and their coordination. With this idea in mind, interaction designers can use a much wider variety of input modalities. This concept can be directly related to "performance" from Klemmer et al. (2006)'s approach (Chapter 2.2.2).

Environmental awareness and skills (EAS) – In addition to the aforementioned characteristics, people sense their surrounding environment and develop skills to interact with it. These are explicit skills such as manipulating, picking up, positioning, and arranging objects, as well as implicit skills that relate to people's physical presence in the spatial environment. McCullough (2004) calls these implicit skills "spatial literacy". Jacob et al. (2008) propose to exploit these human properties for computational artifacts, e.g., by using "location and orientation and display information that corresponds to the user's position in physical space".

Social awareness and skills (SAS) – The last theme that Jacob et al. (2008) introduce focuses on people's awareness of others in their environment and the associated skills for social interaction. These skills include (non-)verbal communication between people, the exchange of physical objects, and the ability to work with others. According to Jacob et al. (2008), TUIs offer promising characteristics to promote co-located collaboration, as they "provide the space and an array of input devices".

Tradeoffs between power and reality: Jacob et al. (2007, 2008) argue that grounding interactions more in the real world "can reduce the mental effort required to operate". Nevertheless, simply building a more reality-based interface does not necessary result in a better interface. Therefore, they recommend that interaction designers deliberately plan the balance between computational power and the level of reality (Figure 5). Most interaction designers make these important decisions between the two dimensions intuitively, without explicit consideration. The authors further suggest that designers "make the 'reality' as large as possible and use the 'power' only as necessary".

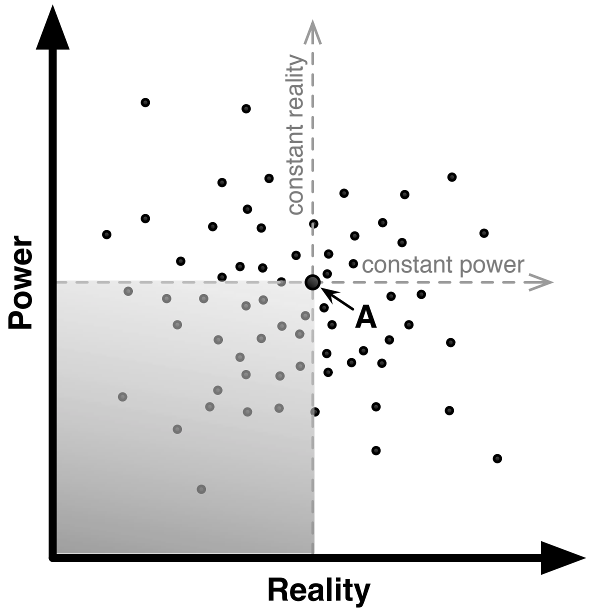


Figure 5 **Power vs. Reality Tradeoff (Jacob et al. 2007)**

Each data point represents a hypothetical interface. Consider the point marked A. The dashed horizontal line represents interfaces with equivalent power. The dashed vertical line represents interfaces with equivalent levels of reality. RBI suggests that adding reality to these interfaces without a loss in power will improve them, and that giving up reality to gain power should be done carefully.

Similar to the work of Klemmer et al. (2006), the goal of RBI interfaces is to give up reality only with appropriate deliberation and only in return for increasing power. In RBI, "power" is a generalization of various computational properties, such as expressive power, efficiency, versatility, ergonomics, accessibility, and practicability. This leads to tradeoffs between power and reality in the design of interactive systems. These tradeoffs are not necessarily bad for the design, but according to Jacob et al. (2008) they must be made mindfully and explicitly. RBI attempts to clarify these tradeoffs by providing explanatory power to understand and communicate "the cost and benefits of such decisions".

Jacob et al. (2008) further argue that "the trend towards increasing reality-based interaction is a positive one", because this shift could reduce the time taken to learn interactions in casual use, might reduce overhead effort in arousal situations, and could encourage improvisation and exploration.

Conclusion: With RBI, Jacob et al. (2007, 2008) have introduced a primarily descriptive framework that allows HCI researchers "to analyze and compare designs, bridge gaps between unrelated research areas, apply lessons learned from the development of one interaction style to another".

In complement to Klemmer et al. (2006), the strength of RBI lies in the analysis of tradeoffs for interaction. Klemmer et al. (2006) propose to "carefully integrate the physical and digital world"; RBI seizes on this suggestion and develops a tool to think about and communicate the advantages and disadvantages derived from shifting certain aspects of an interactive system more into the real or virtual dimension.

However, in contrast to the ideas of Klemmer et al. (2006), the framework developed by Jacob et al. (2007) includes not only real-world interfaces but also interfaces that only "mimic" the real world within a desktop computer, such as virtual-reality interfaces.

2.2.4 Impact

The approaches discussed all try to link the understandings of embodied cognition to HCI. Although they share this common goal, the approaches are at times quite diverse; in other points, they complement each other.

All three approaches emphasize that physical interactions play an essential role in our lives. Especially in situations in which people want to get a grasp on an idea or need to get creative, they break out of the digital world and act in the real world (e.g., brainstorming or sketching on paper and whiteboards, consulting colleagues).

Dourish's embodied interaction (2001) emphasizes the phenomenological perspective of embodiment and the emerging research fields of tangible and social computing. He points out the importance of meaning, which emerges from interaction rather than being fixed by the system. In his perspective, computational artifacts are dead entities that come to life when people interact with them in the real world. Furthermore, people use such an artifact as a medium to act through, rather than acting with the artifact.

Complementary to this phenomenological perspective of embodied interaction, Klemmer et al. (2006) focus on embodied cognition and the consequences for HCI in a more practical manner. They distinguish five themes that open up new perspectives for interaction design. In the end, they come to the conclusion that new UIs should incorporate the real world to the extent possible, as it offers so much benefit. Integrating digital artifacts and features should be done in a very intentional manner.

Jacob et al. (2007, 2008) accommodate the demand to deliberately design new computational artifacts. Their RBI framework offers a structure to analyze the tradeoffs of integrating computational power into reality or *vice versa*.

This thesis incorporates ideas and concepts out of all three approaches. Therefore, the terminology "reality-based interaction" is used as an umbrella term for all UIs that are based on the insights of the above-mentioned approaches.

2.3 Computer-Supported Cooperative Work

As this thesis concentrates on the collaborative use of reality-based UIs, both the research field "Computer-Supported Cooperative Work" (CSCW) and social psychology provide valuable theoretical models and insights that influence the approach and concepts of the PhD project. Therefore, the following section will emphasize on the roots of CSCW, define essential terms and concepts of collaboration, and uncover important insights that have impact on the research focus of this thesis. A further goal of this section is to provide an introduction to the nature of groups and their behavior derived from social psychology.

2.3.1 Background and Definitions

Although Vannevar Bush's (1945) work "as we may think" touched on some related ideas, Douglas Engelbart is often cited as the father of CSCW. In December 1968, he presented a computer-supported meeting environment that paved the way for a variety of inventions, including the mouse, networking, video conferencing, and electronic messaging. The term "CSCW" was introduced in 1984 by Greif and Cashman as the theme for a multidisciplinary workshop. This was the starting point for many researchers, especially HCI researchers, to concentrate on CSCW. The first open conference on this topic was held shortly after the workshop, in 1986. In subsequent years, several distinct conferences and journals have emerged that are still growing today.

Although interest in this research field is extensive, there is no commonly accepted definition of CSCW. A very general definition was stated in the early 1990's by Ellis et al. (1991): "CSCW looks at how groups work and seeks to discover how technology (especially computers) can help them work". Carstensen & Schmidt (2002) state that CSCW addresses "how collaborative activities and their coordination can be supported by means of computer systems." This last definition accentuates the main research focus in the study of CSCW; that is, the social interplay between people working together in groups, communities, or networks. In addition, CSCW can be regarded as an umbrella term for research work from many different disciplines that focuses on the use of computers to support activities of people working together. The question of whether CSCW should be seen as a subfield of HCI or as a distinct research field has been the topic of many controversial discussions and has not yet been resolved.

There are several terms in CSCW that are often used synonymously even though they differ in several crucial aspects. For example, many researchers use the terms "CSCW", "groupware" and "shared interfaces" synonymously. However, the term "groupware" refers to concrete artifacts (e.g., software, hardware, or services) used to leverage group work. Ellis et al. (1991) have defined groupware as "computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment." Another term that is often used in this context is shared interface. Shared interfaces can also be classified as sub category of groupware systems. However, "groupware was primarily targeted at people working together, who were geographically separated, sharable interfaces are designed for people who are physically co-located and where it is considered necessary for them to be copresent" (Rogers et al. 2011). In contrast to these terms, CSCW focuses on the study of such tools and techniques as well as their psychological, social, and organizational effects.

2.3.2 The 3C Collaboration Model

The terminology of "collaboration" and "cooperation" also often lead to misunderstanding, because there are diverse and even conflicting definitions for these terms. Therefore, in this thesis "collaboration" is defined as the global concept of two or more people working together, whereas "cooperation" is an activity of collaboration (Figure 6), as described in the 3C collaboration model of group work (Ellis et al. 1991). Collaboration assumes that the collaborators share resources, follow the same goal or task, and are all involved and interdependent. The 3C model splits collaboration into three interwoven activities that are executed by members of a group: communication, coordination, and cooperation. These activities cannot be regarded as isolated activities; rather, there is a high degree of dependency and a continuous interplay between them.

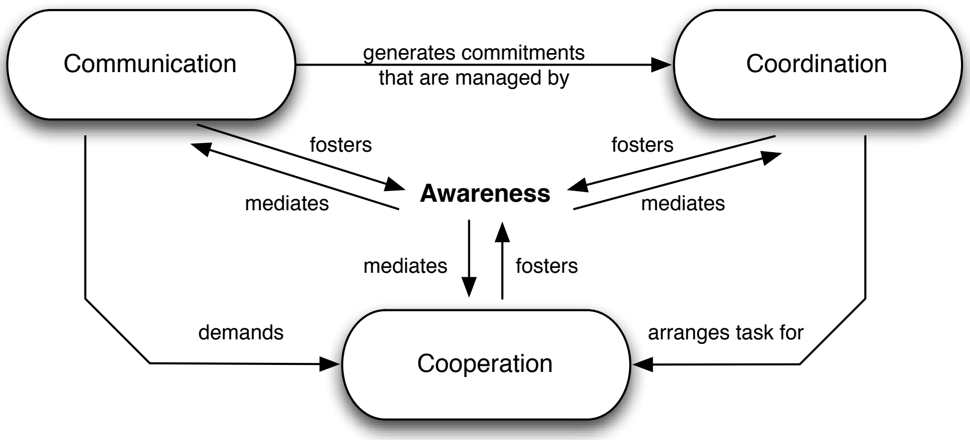


Figure 6 The 3C Collaboration Model of Group Work (Ellis et al. 1991)

Communication: In the 3C model, communication is defined as the exchange of information between collaborators that thereby enables negotiation of commitments. This can occur either verbally (for example, through language) or non-verbally (through a common system of symbols, signs, or behaviors). Rasmussen et al. (1994) described the term as follows: "Communication is the cement of the organization, and the greater the need for coordination and cooperation, the greater the necessity for communication."

Coordination: Tanaka (2003) describes coordination as the "integration and harmonious adjustment of individual work efforts toward the accomplishment of a larger goal." In the 3C model, coordination is seen as a distinct activity allowing management of people, activities, and resources. This activity is needed, for example, when splitting a cooperative task into independent subtasks. Coordination is also often responsible for conflicts in collaboration and can thus obstruct communication and cooperation (Chapter 2.3.4).

Cooperation: According to the definition by Fuks et al. (2005), cooperation is "the joint production of members of a group within a shared space, generating and manipulating cooperation objects in order to complete tasks." In the 3C model, cooperation is seen as the activity of working together in a coordinated fashion on pre-agreed goals and methods instead of working separately in competition.

2.3.3 Theoretical Models of CSCW

In the following section, general models and theories from the research field of CSCW are introduced that will be used in this thesis to classify systems and tasks (Chapter 3.2.4) as well as the scope of the introduced design cases (Chapter 5).

The Group Tasks Circumplex: In 1984, McGrath developed an often-cited circumplex for tasks executed during group work (Figure 7). This circumplex is described as an elaborated classification schema for group-related tasks based on preceding research. Although originally intended for artificial tasks used in laboratory experiments, the circumplex is also applicable to nearly every real-world task. The requirements are that the schema should be (a) mutually exclusive (a task can be distinctly allocated), (b) collectively exhaustive (all tasks can be allocated to a class), (c) logically related, and (d) useful (the schema should point out the differences between tasks that otherwise would not be noticeable). The four quadrants of the circumplex are mapped to the performance processes engaged by the task. These performance processes specify in which task a group is engaged and what characteristics this task has.

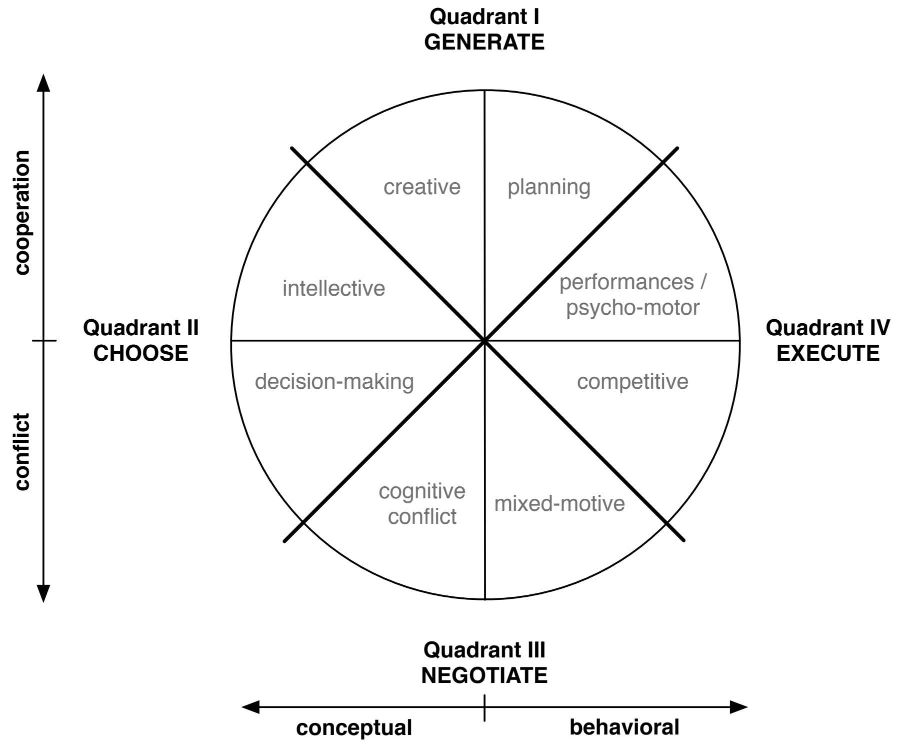


Figure 7 The Group Tasks Circumplex (McGrath 1984)

Quadrant 1 – The tasks associated with this quadrant are described as "generation" tasks. These tasks are divided into "planning tasks" (type 1) and "creativity tasks" (type 2). Planning tasks are those concerned with the development of strategies to solve problems and to generate a plan of action. In contrast, creativity tasks focus on generating ideas, such as in brainstorming sessions.

Quadrant 2 – The next class of tasks is called "choose". Within this class, "intellective tasks" are defined as those that solve problems with a definite answer (type 3). These tasks might include logic problems and other problem-solving tasks with predefined correct answers. In addition, "decision-making tasks" (type 4) are ascribed to this quadrant. These tasks require participants to agree upon an option among different available choices (e.g., polarization studies, preferred-answer studies).

Quadrant 3 – The third quadrant covers tasks concerned with negotiation issues. These include both "cognitive conflict tasks" (type 5) and "mixed motive tasks" (type 6). Type 5 tasks focus on resolving conflicts between differing viewpoints among the participants, while type 6 tasks focus on resolving conflicts of motivational interests (e.g., mixed-motive dilemma tasks or bargaining tasks).

Quadrant 4 – The final quadrant addresses execution tasks. "Contest and battle" tasks (type 7) are described as tasks that resolve conflicts of power. During such tasks, winning a competition is the focus of the participants (e.g., winner-take-all conflicts or competitive sports). Very similar are the "performance" tasks (type 8). In contrast to competitive tasks, these psychomotor tasks are performed against an objective or an absolute standard of excellence (e.g., musical performances or attempts to beat a world record).

The model described above helps to clarify and structure approaches for collaborative IS tasks and systems. It has served as a basis for organization of the group tasks described in this thesis and helped in the planning of user studies, especially in the design of tasks.

Space/Time Matrix: Another widespread classification schema for collaboration processes and groupware systems is the "space/time matrix" (Johansen 1988, Figure 8).

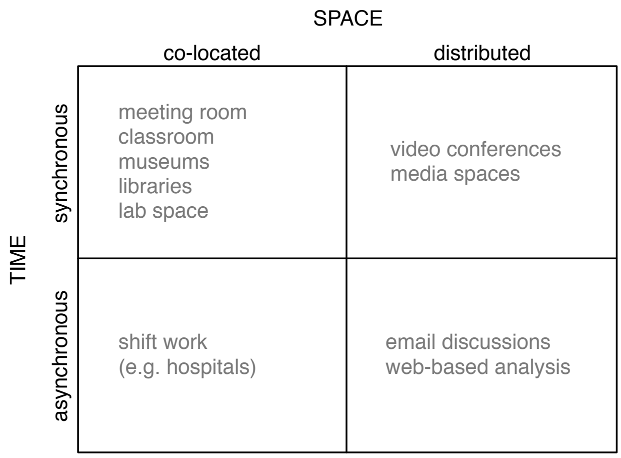


Figure 8 The Space/Time Matrix (Johansen 1988)

This matrix primarily considers the context of collaborative work, splitting it into a spatial context (same or different place, co-located or distributed) and a temporal context (same or different time, synchronous or asynchronous). This concept will be utilized in this theses to describe the design space of tools that aim to support collaborative IS activities (Chapter 3.2).

2.3.4 Collaboration Behavior and Group Dynamics

The research field of CSCW has been enriched by a variety of valuable insights from social psychology. Social psychologists have individuated a number of phenomena that can facilitate or hinder the performance of individuals working collaboratively as a group. In this section, phenomena in collaboration behavior and group dynamics are described that touch on the research questions of this thesis.

Social Facilitation: In 1965, Zajonc analyzed the behavior of individuals in the presence of others, observing that individual arousal increases in such situations. Based on these experiments, he stated the basic principle that increased arousal provokes a more dominant response, a phenomenon called "social facilitation". One real-world example is that people watching a comedy movie in the presence of others laugh more then those watching the same movie alone. Another implication of this research is that the performance of individuals increases in the presence of others when the task is familiar, but decreases when the task is new.

Process Loss: Although working in groups can have advantages, in many tasks groups perform worse than expected. Steiner (1972) called this phenomenon "process loss". Over the course of several experiments, he determined that on average the results of groups are only as good as the individual result of the second-best group member. These process losses can be explained by coordination and motivational problems.

Coordination Problems – Because group members depend on each other, work must be coordinated (Chapter 2.3.2), which can create a variety of problems. In comparison to individual work, coordination is an extra activity requiring effort that otherwise could be devoted to working on the task ("coordination effort").

Other problems in coordination are often a result of "misleading communication" (e.g., differences in terminology or cultural differences) or "misleading goals". An often-described phenomenon also constraining coordination in groups is "production blocking", which occurs when one person in a group "blocks" other group members (e.g., by interrupting) who then forget what they were about to do or say. This problem increases as the number of collaborators grows.

Motivational Problems – Apart from coordination problems, there are also other factors that can affect motivation. Working collaboratively in a group influences the motivation of individual group members in different ways. The motivation problems of individuals working in groups are strongly associated with the coordination problems; group work sometimes enhances individual motivation in comparison to working alone, and sometimes it decreases this motivation.

A typical example is that of "group norms". According to McGrath (1984), groups establish norms regarding how hard members should work. Individuals who work less or more than the norm will be pressured by the others to adhere to the norm.

Another psychological concept along this line is "compliance", by which members of a group are forced into a certain role and fulfill the expectations of this role due to social pressure. This phenomenon often leads to decreased motivation in those affected.

Social Loafing and Social Compensation: "Social loafing" and "social compensation" are additional phenomena that influence the motivation of individuals working in a group. Kravitz & Martin (1986) observed that people sometimes tend to exert less effort in groups than they would when working individually. The underlying reason is that people often think that their contributions are not visible in the whole group outcome. Kravitz & Martin (1986) first analyzed this behavior in an experiment in which two teams pulled a rope in a tug-of-war. By measuring the individual effort of the team members, they observed that the effort exerted by individuals changed depending on several factors, including the number of group members, identification with the group, and the population of the group. This effect was subsequently observed in a wide variety of experiments in both laboratory and real-world situations, using both physical and cognitive tasks.

Karau & Williams (1993) developed a theoretical framework of social loafing (Figure 9) that can be used to analyze and describe the phenomenon. The model predicts that when people think that their contribution is unique or that the contributions of the others are worse, they work harder ("social compensation"). The feeling of being necessary to achieve a positive outcome for the group may enhance individual motivation. On the contrary, when people think that their effort is not necessary to complete the group's task, their motivation and thus their individual effort decreases ("social loafing").

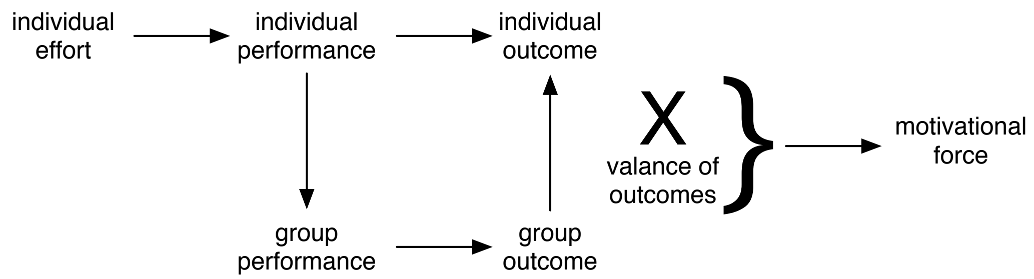


Figure 9 Collective Effort of Social Loafing (Karau & Williams 1993)

Conformity: The psychological concept of "conformity" is described as committing to a conformal behavior or opinion of a group even when it is contrary to an individual's personal position. Asch (1955) observed this phenomenon of social influence in an experiment in which participants were asked to compare the length of different lines with a standard line. In most cases, the participants determined the correct answer when they did the task individually; however, in an artificial group situation in which preselected group members were asked by the experimenter to propose a wrong answer, participants agreed on a wrong result. They offered a number of different justifications for their behavior: for example, they didn't want to upset the experiment by disagreeing; they thought their eyesight might be faulty, or they didn't want to "appear different". The strength of this effect also depends on the cultural background of the group members; studies have found Japanese and American participants to be the most conformist and French and Portuguese participants the least (Benyon 2005).

2.3.5 Impact

This section emphasized important theoretical concepts from the research fields of CSCW and social psychology that have influenced the research for this thesis. After an introduction to the background and terminology of CSCW, valuable models including the task circumplex and the space/time matrix have been introduced. These models will be used in later chapters to describe group-related tasks and to classify design cases and related work. Furthermore, insights from social psychology on the differences in behavior between individuals and groups have been introduced. In the following chapters, these phenomena will be addressed in the description of design cases and experiments.

2.4 Chapter Summary

In this chapter, I have laid out the theoretical foundation of the thesis. Three overall areas of research that affect my approach have been taken into consideration.

HCI and cognitive science: HCI and cognitive science are closely related research fields. Cognitive science focuses primarily on the theoretical concerns of the human mind; HCI utilizes findings that emerge from cognitive science to develop and explore UIs. This thesis analyzes two theoretical models – activity theory and embodied cognition – that provide a new perspective of the users of interactive systems as multifaceted subjects embedded in a social and physical context. The embodiment theory in particular emphasizes that human skills (mental and physical) are directly derived from experiences with the physical and social world.

Embodied and Reality-Based Interaction: As a consequence of theoretical and technological progress, a number of HCI researchers have attempted to define models and principles that allow more natural interaction between users and computational artifacts. This section introduces approaches that recommend greater emphasis on interaction with the real, non-digital world in the design of interactive systems: "To improve the understanding of digital systems, UIs are based on the rules of the physical world. In addition, the everyday knowledge of the users is regarded as an instrument to design simple and effective computer systems. For example, reality-based UIs call upon the social skills of the users to enable collaborative work" (Jacob et al. 2008).

Computer-Supported Cooperative Work and Social Psychology: As the core of the thesis focuses on collaborative processes, the last section of this chapter outlines important insights from CSCW and social psychology. After a short abstract, which describes the evolution and the contradictions of CSCW as a field, the term *collaboration* is defined as a global concept of people working together, which according to the 3C model can be split into three activities: coordination, cooperation, and communication. Social psychology provides understanding of behavior patterns and the dynamics of people working together in groups. For example, the concepts of social loafing and social compensation offer explanations for how active people engage in group activities.

Key Points

- HCI and cognitive science are closely related research fields and can thus profit from each other in various ways.
- Theories from cognitive science, such as the embodied view of cognition and activity theory, are utilized in several HCI models.
- CSCW and social psychology offer explanations of how people work together in groups that can be utilized in the planning of this thesis.

3 Collaborative Information Seeking

"But things can happen in a band, or any type of collaboration, that would not otherwise happen."

Jim Coleman (American Actor, 1961 –)

Contents

In the following chapter the research domain of this thesis, namely collaborative IS will be introduced. Therefore, IS as distinct research field will be discussed. Collaborative processes will be highlighted as essential part of IS. Thereafter, the focus will be put on the motivations to search collaboratively and which group types and configurations as well as tasks and strategies can be found during these activities. Subsequently, the design space for computational tools that are aimed at supporting collaborative IS is shown together with some selected examples. At the end of this chapter, several reality-based approaches that are designed for collaborative IS are introduced that constitute the related work of this thesis.

3.1 Information Seeking

3.1.1 Definitions and Related Research Fields

Before turning the focus to information seeking (IS), it is important to clarify what the term "information" represents. There are various and diverse definitions of information. Many researchers define information as contextualized data; for example, Tapscott (1998) stated, "When organized and defined in some intelligible fashion, then data becomes information". Another aspect was added by Kuhlen (1999), who noted that "information is knowledge in action". Von Foerster (1971) went one step further, claiming that "information is the natural process through which we gain insight".

Based on these definitions – with the broader meaning of information in mind – interaction with information (including IS) "takes place within a context that is physical, social and activity-centered building also on the prior knowledge and experience of the individual or community" (Blandford & Attfield 2010). Often, people do not perceive "information seeking" as a distinct activity. It occurs during their work processes, "sometimes intentionally, sometimes by chance; sometimes to seek particular facts, sometimes to build up an understanding; sometimes with well-defined search criteria, and sometimes without a clear understanding of what information might be available and might be useful" (Blandford & Attfield 2010). When developing new UIs that seek to support IS, it is essential to understand people's working practices and the situations in which they arise.

Various research fields related to IS offer perspectives to account for searching options and behaviors. For example, *personal knowledge management* (PKM) focuses on individuals interacting with information. *Finding* and *gathering* information are essential activities of PKM that have been observed by Sellen & Harper (2002), among others. Sellen & Harper (2002) described *finding* as "locating specific facts, which might be maintained for reference on a temporal basis" and *gathering* as "locating and sorting information to address questions which were difficult to specify". In contrast to PKM, *information retrieval* (IR) emphasizes technologies that help to find and represent information. Whereas other research fields concentrate on users, IR focuses on the technical aspects, such as the development of algorithms to improve precision and recall. However, IR assumes that users are able to define their information needs, often in an abstract query language, and that they are able to interpret results. Another research direction, *sensemaking*, focuses on the intentions of people seeking information and how they process the information to construct meaning. Thomas et al. (1993) defined *sensemaking* as "the reciprocal interaction of information seeking, meaning ascription and action". By this definition, IS can be seen as a (part of a) sensemaking process.

3.1.2 IS Models and Approaches

In the past, IS had a strong library science tradition and thus its primary emphasis was on IS in physical libraries. With distribution of information via the Internet and the emergence of digital libraries, the focus has shifted towards a broader perspective of IS. As a consequence, IS researchers have tried to develop more complete explanatory approaches to how people search.

A result of this historical evolution is the development of numerous models with various complementary and/or contradictory views of IS. Some of these models emphasize behavior, some concentrate on temporal aspects, and still others focus on affective issues of information seekers. The next sections will briefly outline some complementary concepts of various IS models.

Marchionini's model (1995) stresses the nature of IS as an *iterative process*. The information seeker is an unstable variable in this process, who is constantly changing (e.g., his or her goals, thoughts, and perspectives). Marchionini further underscores the *opportunistic aspect of searching*, i.e., that information seekers identify and pursue new opportunities while in the process of searching. Pirolli & Card (1995) introduce a similar concept in their "Information Foraging" model, observing that information seekers often have to decide whether to continue or to follow a newly discovered direction. The researchers report that information seekers implicitly make their choice based on comparisons of the perceived information values of the two possible directions.

Other researchers have centered their attention on IS behaviors (e.g., Ellis 1989). A widely accepted view in IS is that information seekers constantly switch their searching strategy between *browsing* and *searching*. Ellis (1989) defines *browsing* as "semi-directed searching in an area of potential interest"; in a complementary fashion, Makri et al. (2008) define *searching* as "formulating a query in order to locate information". More concisely, Bates (1989) defines browsing as a "way we find information that we do not know we need to know" and (directed) searching as a "way we find information that we know we need to know".

In their "Information Journey", Adams & Blandford (2005) further accentuate that IS is "an *embedded and interleaved activity* in a knowledge worker's process". Contexts in IS processes include social structures, available artifacts, and past experiences of information seekers.

Blandford & Attfield (2010) categorize the seeking context hence in a temporal, physical and social context, which are addressed in the following models.

The "Berrypicking" model of Bates (1989) describes the temporal aspect with the idea of *search evolving over time*. She argues that new information opens new perspectives and thus creates new ways of enquiry. This aspect is therefore regarded as the stage of an information seeker in the IS process as well as experience and expertise gathered over time. This experience and expertise can either be knowledge about the seeking domain (e g., familiarity with particular information resources or experience in the assessment of results in a certain domain) or general expertise in IS through seeking in other domains (e.g., applying well-defined seeking strategies for query formulation and refinement).

An additional aspect of IS is the *interplay between the physical and the digital*, which includes information artifacts and information spaces. For example, Sellen & Harper (2002) highlighted the benefits (e.g., readability, affordance, sense of privileged access, spatial arrangement) and drawbacks (e.g., no remote access, difficulty in revising and replicating, static information display) of paper as a physical information artifact, that is, an externalized artifact important for communicating and mediating (as defined in activity theory, Chapter 2.1.3). In the same way, digital information artifacts also have inherent strengths (e.g., digital functionalities such as full-text search, indexing, and duplicating) and drawbacks (e.g., information and materiality lost through the digitization process, such as the feel and smell and also the bindings of books). Sellen & Harper (2002) believe that it is essential for people to make use of digital and physical documents as complementary artifacts in order to benefit from both worlds. Other researchers have observed similar behavior with the input techniques "pen" and "keyboard" (Duguid 1996): "technologies that perform the 'same' function do not necessarily supersede each other, but may instead be complementary, depending on the task at hand".

Dörk et al. (2011) round out this vision of IS with a further viewpoint, called "Information Flaneur", which regards the mind, heart, senses, and soul of an information seeker as curious, creative, and critical person. Thereby, they broaden the view of IS from information work to an *everyday life activity* "driven by interest, desire and an open mind". With this approach, the researchers seek to break with negative concepts like needs and problems, instead encouraging consideration of the *positive information experience*. Kuhlthau (2004) contributed an additional perspective in her "Information Search Process" (ISP), in which she described certain *feelings*, *thoughts*, and *actions* that occur during the progress of six stages.

From an initial uncertainty, information seekers move through a process of exploration to a point of understanding. The turning point in her process is the formulation of the focus.

She points out that especially at this stage, mediators (other people who become involved in the search) may be required for progress in the seeking process to be made. This perspective of IS as a *social activity* concurs with the findings of research by Evans & Chi (2008), who observed that in various stages of the search process, the information seeker can engage with other people. Blandford & Attfield (2010) go so far as to state that "the majority of information interactions take place within a social context – whether that be groups of information professionals, peers with similar or different roles or subject matter experts". This perspective of search as a social and collaborative activity will be explored in detail in the next section.

3.2 Collaborative Information Seeking

Several IS models and approaches have pointed out the importance of social aspects in search. Morris & Teevan (2010) defined social search as the "process of finding information with the assistance of social resources", whether these are implicit resources (e.g., rankings in search algorithms based on social aspects) or explicit resources (e.g., rankings of search results from other users, face-to-face collaboration with other people) for the information seeker. Collaborative IS is thus a part of social search and is defined as "the process of more than one person searching in collaboration with others for a shared goal". In the next few sections, collaborative IS will de discussed in detail.

3.2.1 Motivations to Seek Collaboratively

Morris & Horvitz (2007) reported that nearly everyone does collaborative searches, from library visitors, students, senior citizens, families, to information workers in various fields (e.g., education, finance, healthcare, and the law). The motivations behind collaborative IS are also very diverse and are often a mixture of intrinsic and extrinsic factors.

Some collaborative seeking situations emerge simply through *shared interest* in the topic; others occur because people have the feeling that *collaborative results are more valuable*. This latter aspect is a consequence of the fact that in many collaborative search situations, users are able to benefit from their collaborators' different search strategies and different perspectives on the knowledge domain. As a side effect of working with others, people can *improve their individual search skills* – for example, when they are unfamiliar with technology (as is often the case for the elderly).

In many cases, people expect that a seeking group will be *more productive* due to reduction in unnecessary or redundant work; for example, a group can cover a greater subset of the relevant information space using coordinated division of labor (Chapter 3.2.3). In addition, groups often attain *higher confidence* in the quality of their results through the collaborative development process.

Some people join a collaborative search session for *social reasons*, such as a feeling of obligation (e.g., parents helping their children to seek information for a homework assignment), a desire to earn social recognition (e.g., experts offering unsolicited advice to novices to show off their superior knowledge), or simply a desire to connect with other people.

3.2.2 Group Types and Configuration

The types of collaboration within a group are very important in the study of collaborative IS and the design of interfaces. Blandford & Attfield (2010) introduced three different types of groups that arise in collaborative IS: *experts and consumers*, *information intermediaries*, and *communities of practice*.

Expert and consumers – In some situations, people require the assistance of others to make progress in their IS process (Kuhlthau 2004). These information seekers often then rely on the expertise of professionals in the field, thus collaborating in an expert and consumer situation (e.g., patients and healthcare professionals). Blandford & Attfield (2010) observed that people develop "new ways of interacting with such professionals as they gain access to more […] information resources".

Information intermediaries – Similar to the expert and consumer situation is collaboration with information intermediaries. In contrast to the expert and consumer setting, intermediaries do not inherently possess expertise in a single domain, but rather serve as mediators between information consumers and information sources. In the past, this role was almost exclusively assumed by librarians, but with modern possibilities of information access, other types of intermediaries have become common. These people contribute during collaboration by understanding the information needs of other information seekers and attempting to support the formulation of those needs. They might also assist by suggesting alternative search terms or by prioritizing resources.

Community of practice – The final group type is that in which collaborators all assume the same role. This type of group, called a "community of practice" (Wenger 2006), may include collaborators that have a formal, informal, or situated relationship – for example, work colleagues, families, or library patrons, respectively. Depending on the group configuration, such groups may evolve effective practices in response to new opportunities and needs. Rimmer et al. (2008) described how beginning PhD students profited in such a community of practice, obtaining new research strategies by observing the interactions of their supervisors and other colleagues as they searched for and worked with information.

In addition to the type of collaboration, Morris & Horvitz (2007) introduced several factors that determine the configuration of groups: *direction*, *strength of relationship*, *longevity*, and *group size*.

Direction – The factor of direction is again divided into *symmetric* and *asymmetric* collaboration. In symmetric collaboration, the collaborators assume the same role, whereas in asymmetric collaboration, they fulfill different roles in the seeking process (e.g., based on their familiarity with the technology involved, their position in the hierarchy, or their specific expertise).

Strength of relationship & longevity – The strength of the information seeker's relationship to other group members (e.g., their family, colleagues, or randomly assembled collaborators) is also a factor that influences how much effort people will contribute to a collaborative search. A related factor is the longevity of a group: in comparison to a long-standing collaborative group, an unstable, short-term group situation will be less capable because collaborators have insufficient knowledge of the individual skills and behaviours of group members.

Group size – The final factor that influences the group configuration, according to Morris & Horvitz (2007), is the group's size. Amershi & Morris (2008) observed in a diary study that shared group tasks in IS are usually executed in pairs (80.7 percent) or with three or four collaborators (19.3 percent). No larger group was observed in this study, although Amershi & Morris (2008) stated that this may due to the lack of available tools that would permit such a situation.

3.2.3 Tasks and Strategies

Amershi & Morris (2008) reported that collaborative IS activities tend to be more sophisticated and involve larger processes (Chapter 3.1). Social interactions can play an important role at each stage of the IS process (Morris & Teevan 2010); such activities can encompass a variety of collaborative tasks, including formulating and refining an information query, filtering results, and assessing and selecting resources. According to the group tasks circumplex (Chapter 2.3.3), tasks can be found in all quadrants. Some common tasks mentioned by Amershi & Morris (2008) are travel planning, online shopping, literature searches, finding technical information, fact-finding, social planning, and searching for medical information or real estate.

During an IS process, people apply different strategies, usually browsing at the beginning of a seeking process and turning to directed searching later on when the information need becomes more focused. Twidale et al. (1997) added another dimension for seeking strategies in collaborative settings, observing that group collaboration is either *process-related* or *product-related*. Process-related collaboration consists of all activities related to how people find information (e.g., query formulation, focus formulation); product-related collaboration involves activities that concern the search results as "search products" (e.g., assessment and processing of search results).

However, Bruce et al. (2003) claim that "not all actions related to satisfying a collaborative information task take place collaboratively". Often, the group members apply a "divide and conquer" strategy, in which the collaborators work on separate tasks on their own without cooperation. This strategy, which involves sharing the product of a search rather than the process, is called *loosely-coupled* collaboration, in contrast to *tightly-coupled* collaboration, in which all collaborators work cooperatively together. In the most collaborative IS situations, there is regular alternation between these two strategies. Splitting up the group search tasks into several sub-tasks can either be accomplished by uncoordinated (brute force) or coordinated (division of labor) efforts.

3.2.4 Collaborative IS Design Space

Developers have access to a very broad design space for support of collaborative search. The following section will describe these options and highlight their advantages and drawbacks by means of examples. These collaborative search options are categorized by the dimensions of space and time, as introduced in the space/time matrix (Chapter 2.3.3).

Remote vs. Co-Located: When users share an information need but find themselves in different locations, they often collaborate *remotely*. However, despite modern technological options (e-mail, chat clients, and video conferencing tools), this can often be a problematic undertaking. An example of a challenge in remote settings is that for many IS activities, the mutual awareness of the collaborators is vital. Furthermore, in remote collaboration, it is more difficult to coordinate efforts and to communicate in an effective manner. Another challenge is that in remote collaboration often the contribution of individuals is not instantly visible for other group members and outstanding people, which may cause motivational problems (Chapter 2.3.4,"social loafing").

Morris & Horvitz (2007) attempted to address these challenges in SearchTogether, a system that allows several information seekers to collaborate remotely on Web searches (Figure 10). The system is primarily intended to support awareness, division of labor, and persistence with the goal of enhancing remote IS in synchronous and asynchronous groups. SearchTogether combines various widely used technologies (instant messaging, comments, and ratings) with several newly developed technologies (automatic division of labor, shared summaries, query awareness, visitation awareness, and state persistence). In an evaluation study, Morris & Horvitz (2007) determined that the features aimed at increasing awareness (query histories, visitation histories, ratings, and comments) were regarded as most valuable by the participants. Even the features that were designed to allow a coordinated division of labor and persistence (e.g., integrated messaging and summaries) were used as awareness mechanisms.

Figure 10 **The SearchTogether Client**

(a) Integrating messaging, (b) query awareness, (c) current results, (d) recommendation queue, (e-g) search buttons, (h) page-specific metadata, (i) toolbar, (j) browser (Morris & Horvitz 2007)

The results of the SearchTogether user study demonstrate that the awareness of other group members is critical for the success of collaborative IS. Although SearchTogether has some valuable features that enhance this aspect in remote IS, the best awareness can still be achieved in a face-to-face or *co-located* situation.

In settings of co-located collaboration, IS situations often result in collaborators sharing a single device. This may be due to resource limitations or pedagogical justifications. For example, Amershi & Morris (2008) observed the phenomenon of "backseat drivers", in which people sit behind or beside a collaborator who is controlling a PC. The backseat driver contributes to the collaboration by suggesting search terms and strategies that are then executed by the other collaborator. Various problems may arise as a consequence of this type of collaborative setting: for example, the collaborator controlling the PC might ignore suggestions, or might only satisfy the wishes of the backseat driver at the expense of his or her own ideas. A study by Amershi & Morris (2008) emphasized the problems created by this setting, highlighting the variety of challenges that must be faced when several information seekers share one computer (Table 1).

Table 1 Challenges in sharing one computer

Challenge	Description
Difficulties in Contributing	Group members without access to the computer's mouse and keyboard must rely on their "driver" to act on their suggestions. Conversely, "drivers" may be so busy carrying out the suggestions of others that they do not have time to propose their own ideas.
Lack of Awareness	More dominant or vocal group members can overshadow the contributions of others.
Lack of Hands-On Learning	Group members without control of the PC's input devices lose the opportunity to gain direct technological skills.
Pacing Problems	The user operating the input devices may change or scroll webpages too quickly or slowly for the reading abilities of other group members.
Referential Difficulties	Pointing at the shared display to establish context or to refer to specific on-screen items may be difficult, depending on the group size and configuration.
Single-Track Strategies	Although group members might have different search strategies (e.g., different query terms they want to try or different links the group should follow), the shared display requires the group to follow only a single path through the information space.
Information Loss	At the end of the collaborative session, group members have no record of what they have accomplished to take away with them.

From: Amershi & Morris (2008)

Amershi & Morris (2008) observed in a diary study with information workers that in the majority of cases, co-located seeking situations occurred as spontaneous and brief events. Therefore, they suggest that in order to support co-located collaboration, the design of IS systems should "keep system costs minimal, provide a history of group's suggestions, enable distribution of control among group members, include consensus facilities, provide awareness mechanisms and share context and make it easy for each participant to take relevant information away from the shared setting".

In recent years, several research projects have focused on facilitating co-located IS. Many systems have been designed with separate input devices for each collaborator; sometimes this setting is complemented by one shared display for all collaborators. CoSearch (Amershi & Morris 2008), for example, is a system in which collaborators share one PC, but are able to use their mobile phones to contribute to the collaboration (Figure 11). Each group member is thus able to control an individual mouse cursor on the shared PC via his or her phone. In addition, each collaborator can read documents on their private phone's display at their own pace. An evaluation study comparing CoSearch with a shared PC condition and a condition with each person using their own PC showed that CoSearch preserved the stimulating group dynamics (e.g., communication and collaboration behaviors) of the shared PC condition, while enabling distributed control and division of labor. In terms of group awareness, the shared PC condition was rated better than CoSearch. However, Amershi & Morris (2008) observed greater frustration in observers and expert information seekers in the shared PC condition. The participants stated that limited efficiency and lack of individual control in the shared PC condition were the causes of this frustration.

Figure 11 CoSearch

(a) Four students searching collaboratively with CoSearch. One student is operating the shared PC, the others contribute to the search with their mobile phones; (b) The CoSearch interface in detail (Amershi & Morris 2008).

Several collaborative IS systems that use emerging technologies such as multi-touch tabletops are also related to co-located IS systems. These will be described in chapter (3.2.5) in more detail.

Asynchronous vs. Synchronous: Another dimension for categorization of groupware and collaborative IS systems is the temporal pattern of their use. *Asynchronous* collaboration in IS may occur in tasks that extend over multiple separate sessions (Morris & Teevan 2010). When asynchronous collaboration is supported, it becomes possible to "collaborate with the future self". However, systems that allow only asynchronous collaboration must address the problem that a great deal of context information may be lost between sessions. Thus, the main challenge for such systems is to preserve the states of individual sessions for later retrieval. In addition, in an asynchronous collaboration session, it is often problematic to determine the future value of information items.

One project that offers mechanisms to allow groups to seek asynchronously is S^3 (Storable, Sharable Search) (Morris & Horvitz 2007, Figure 12). This system supports collaborative remote Web search by providing features such as implicit capturing of the process and products of multiple search sessions. This automatically generated and stored representation of search states can be shared with collaborators to advance IS activities. In this way, the authors attempt to reduce redundant work in a group and to conserve the context of an activity across several sessions with the input from multiple collaborators.

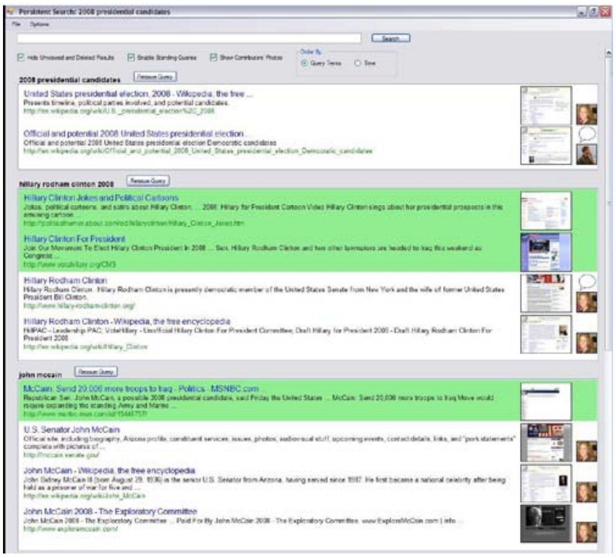


Figure 12 **S^3 (Storable, Sharable Search)**

"The title, URL, and thumbnail for each page visited […] is presented beneath the query terms […]. The user who contributed each page to the investigation is depicted via a thumbnail, and the presence of comments is indicated by a speech bubble icon" (Morris & Horvitz 2007).

In contrast to asynchronous collaboration, *synchronous* collaboration situations emerge in situations in which group members simultaneously undertake their search task. Most of these situations take place in physically co-located settings. This real-time collaboration is characterized by direct communication and coordination (3C model, Chapter 2.3.2). Systems that allow synchronous collaboration must address the challenges of providing support for synchronous input, allowing a variety of roles, and implementing awareness features by which collaborators can track the actions of other group members. For example, CoSearch (Amershi & Morris 2008) supports simultaneously occurring inputs from different devices with an input-queuing mechanism that completes one input after another sequentially. Other systems, such as those that rely on multi-touch input devices or tangible UIs, are able to process multiple inputs in parallel.

3.2.5 Reality-Based UIs in Collaborative IS

In modern digital IS systems, collaborative search is often not sufficiently supported. The obvious limitations of desktop or terminal PCs controlled by mouse and keyboard do not offer appropriate mechanisms for collaborative work. To overcome this deficiency, a number of researchers (among them, Morris et al. 2006, Hartmann et al. 2009, Isenberg & Fisher 2009, and Morris et al. 2010) have proposed the use of multi-touch tabletops for co-located collaborative IS activities. These researchers theorize that the horizontal form factor of a tabletop interface will democratize the interactions between multiple users through the possibility of simultaneous touch operations. Furthermore, these settings promise more natural interactions between users in a way that will enhance the perception of the interactions, gestures, and postures of others during work and discussions. TUIs are also proposed as a tool to support collaborative activities (Hornecker 2002). Through the possibility of parallel manipulation and the physical capabilities of these interfaces, they are able to further enhance co-located, collaborative activities using digital information systems.

In recent years, several systems have been developed that explicitly or implicitly adapt reality-based concepts for collaborative IS. The following section introduces selected approaches in terms of *group types and configurations* and the *tasks and strategies* they support, as well as their classification in the *design space*.

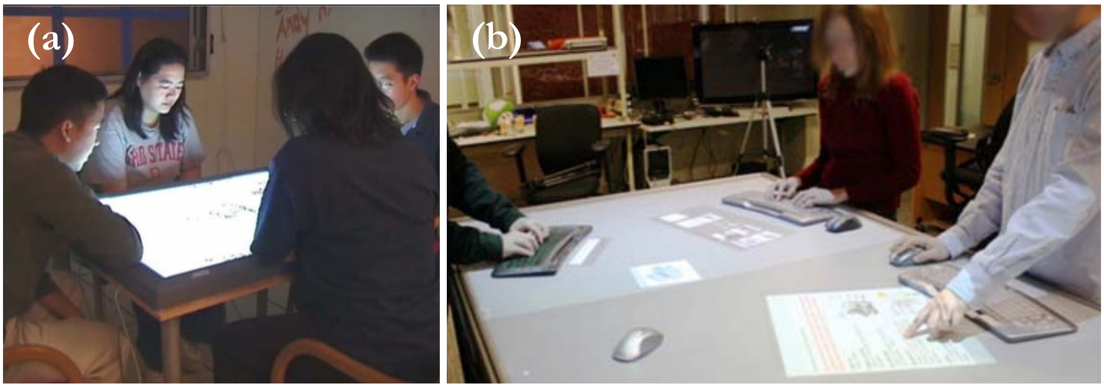


Figure 13 **TeamSearch and FourBySix**

(a) "A […] group uses TeamSearch […] to find photos from a metadata-tagged repository" (Morris et al. 2006); (b) "A group gathers around FourBySix, a […] tabletop that supports mouse and keyboard input, to conduct a collaborative search task" (Hartmann et al. 2009).

TeamSearch: One research project focused in this direction is TeamSearch (Morris et al. 2006, Figure 13a). This system enables the collaborative specification of Boolean queries (choose and negotiate tasks, according to the group task circumplex, Chapter 2.3.3) in small groups conducting searches in a digital photo repository (co-located/synchronous). As query formulation in collaborative settings is a relatively unexplored domain, TeamSearch provides valuable insights. In a user study, a multi-touch table was used to explore two different interface conditions: a collective (tightly-coupled) interface, in which all collaborators constructed a query together, and a parallel (loosely-coupled) interface, in which each group member defined a query individually. In terms of efficiency and quality of search results, no significant differences could be found, but the collective interface showed advantages in terms of the collaboration and awareness of the group members. In the subjective evaluation of the conditions by the participants, the collective interface was rated significantly better. Morris et al. (2006) explain the subjective results by the observed phenomenon that some participants had difficulties forming Boolean queries. These participants in particular were able to learn from others in the collective condition (situated learning, Chapter 2.2.2).

FourBySix Search: Another system that supports group search with the help of a multi-touch tabletop is FourBySix Search (Hartmann et al. 2009, Morris et al. 2010, Figure 13b). This system, designed for collaborative Web search, uses a four-by-six-foot surface with overhead projection (choose and negotiate tasks, according to the group task circumplex, Chapter 2.3.3). To address the challenge of text input on a tabletop, FourBySix Search allows information seekers to use hardware keyboards on the surface as the input modality for query formulation. The system also recognizes the keyboards' locations and orientations, which serve as placeholders for the information seekers. Using the distance and orientation of the keyboards, the system predicts the collaborative work style of the group: either loosely-coupled (keyboards arranged far apart from each other) or tightly-coupled (keyboards arranged in direct proximity, next to or facing each other). This technique allows seamless and implicit transitions between these work styles, simply by arrangement of the keyboards on the tabletop. Furthermore, as the system can track the orientation of the keyboards, it can present information in the appropriate orientation. However, the tabletop is limited in size, and the physical keyboards can generate clutter and obscure large parts of the screen.

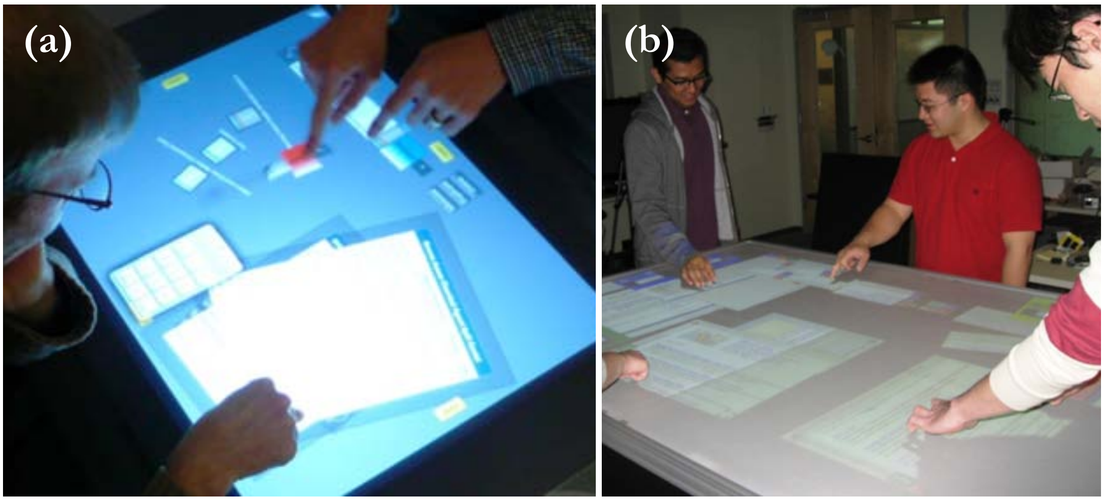


Figure 14 Cambiera and WeSearch

(a) Two users collaborate around Cambiera (Isenberg & Fisher 2009); (b) WeSearch: "Each group member has a color-coded toolbar in which they can enter queries […] and a marquee containing awareness information. Spread around the table are several browsers, clips, and containers."(Morris et al. 2010).

Cambiera: Isenberg & Fischer (2009, Figure 14a) introduced the Cambiera system, which encourages co-located collaboration on a multi-touch tabletop in pairs and small groups. The special focus of the system design is that high awareness among group members is an important requirement for performing visual analytics (choose, negotiate, and generate tasks, according to the group task circumplex, Chapter 2.3.3). To this end, Isenberg & Fisher (2009) introduced the concept of collaborative brushing and linking inspired by the information visualization technique (Buja et al. 1991). When an information object is modified or touched, all instances of this object are highlighted. In this way, the actions of collaborators are instantly visible to all group members. Furthermore, if the search results of two collaborators contain the same documents, Cambiera offers a visible cue showing this overlap. In a user study (Isenberg & Fisher 2010), the researchers intensively analyzed the closeness of team collaboration and the influence of the group work on task performance. The study showed that teams that worked tightly together were more successful in completing the task and required less support.

WeSearch: The multi-touch tabletop system WeSearch (Morris et al. 2010, Figure 14b) was also designed for collaborative Web search and sensemaking (choose, negotiate, and generate tasks, according to the group task circumplex, Chapter 2.3.3), seeking to leverage the benefits of tabletop displays for face-to-face collaboration in small groups. The system provides features that enhance group awareness (e.g., color-coding and marquees) as well as clips and containers for preliminary search results to support "sensemaking as an integral part of the search process" (Morris et al. 2010).

The WeSearch system was also part of a user study showing that tabletop displays were effective platforms to facilitate collaborative Web search. The study also found that tabletop displays enhanced awareness of the actions of group members and of artifacts such as search criteria, and that the displays allowed natural transitions between tightly- and loosely-coupled work styles.

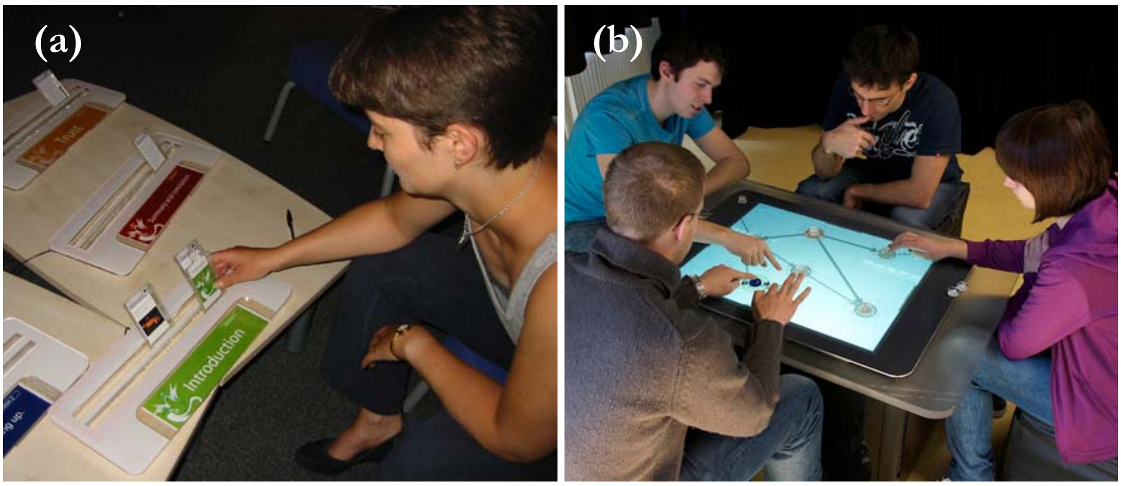


Figure 15 Query by Argument and Facet-Streams

(a) Information seekers are able to formulate their information needs collaboratively by placing tangible card objects in physically constrained card racks (Blackwell et al. 2004); (b) Three collaborators sharing a tabletop using Facet-Streams (Jetter et al. 2010).

Query-by-Argument: Another approach to support co-located IS activities, using TUIs rather than a tabletop, was introduced by Blackwell et al. (2004) with their Query-by-Argument system (Figure 15a). This system allows collaborators to develop and express an information need by arranging RFID-tagged argument cards in physically constrained card racks (choose and negotiate tasks, according to the group task circumplex, Chapter 2.3.3). During a discussion in a group, each participant is thus able to contribute equally, simply by moving a card. The cards serve further as placeholders for virtual information items that contain the contribution (e.g., relevant text passages). The setting is additionally complemented by a peripheral display that continuously suggests related information based on the arrangements of cards on the table. In this way, the group is able to iteratively construct their information needs by the spatial (re)arrangement of tangible cards.

Facet-Streams: With Facet-Streams, Jetter et al. (2010, Figure 15b) introduced a hybrid interactive surface for co-located collaborative product search (choose and negotiate tasks, according to the group task circumplex, Chapter 2.3.3). This system uses techniques of information visualization with tangible and multi-touch interaction to "materialize" collaborative search on an interactive surface. Applying a visual and tangible stream metaphor, Facet-Streams enables information seekers to make use of the expressive power of faceted navigation (Hearst 2009) and Boolean logic without the need to formulate queries in complex formal notation. Because users must only choose facets and values, the system works without any (physical or virtual) keyboard. Two user studies demonstrated the potential of hybrid UIs with regard to their visual and physical capabilities as well as the simplicity of interaction. The authors observed increased awareness and better mutual support among collaborators and seamless transitions between tightly-coupled cooperation and loosely-coupled parallel work.

Overview: The research projects discussed reveal that multi-touch tabletop displays offer promising possibilities for co-located collaborative work: equal access to information, smooth transitions between individual and collaborative activities, and more balanced participation. In addition, hybrid interactive surfaces demonstrate additional positive qualities for collaboration, including parallel physical manipulation and increased awareness and better mutual support among collaborators. Table 2 gives an overview of the introduced research projects.

Table 2 Overview of introduced RBIs for collaborative IS

System	Setting	Space / Time	Group Configuration	Group Type	Tasks Type	IS Strategies / Work Style
SearchTogether (Morris et al. 2006)	Multi-touch tabletop	Co-located / Synchronous	Community of practice	Small groups (up to four people)	Specification of Boolean queries (choose, negotiate)	Loosely-coupled, tightly-coupled
FourBySix Search (Hartmann et al. 2009, Morris et al. 2010)	Multi-touch tabletop, physical keyboards	Co-located / Synchronous	Community of practice, experts and consumers	Small groups	Web search (choose, negotiate)	Loosely-coupled, tightly-coupled
Cambiera (Isenberg and Fischer 2010)	Multi-touch tabletop	Co-located / Synchronous	Community of practice	Pairs, small groups	Visual analytic tasks (choose, negotiate, generate)	Loosely-coupled, tightly-coupled
WeSearch (Morris et al. 2010)	Multi-touch tabletop	Co-located / Synchronous	Community of practice	Small groups	Web search and sensemaking (choose, negotiate, generate)	Loosely-coupled, tightly-coupled
Query-By-Argument (Blackwell et al. 2004)	Tangibles, peripheral display	Co-located / Synchronous	Community of practice	Small groups	Information retrieval query formulation (choose, negotiate)	Tightly-coupled
Facet-Streams (Jetter et al. 2010)	Multi-touch tabletop, tangibles	Co-located / Synchronous	Community of practice, experts and consumers	Small groups	Product search (choose, negotiate)	Loosely-coupled, tightly-coupled

However, to date the influence of reality-based UIs on collaborative work and especially in IS has not been explored in detail, and efforts to identify the mechanics of collaboration in these tasks and how reality-based UIs might support them have been insufficient. The aim of this thesis, therefore, is to provide detailed examination of whether and how interaction, communication, and strategies of users change during collaborative exploration and seeking activities depending on the type of interface.

3.3 Chapter Summary

Although some critics view collaborative IS as an artificial task that would never take place in real working practice, there are many situations and motivations that would encourage connecting to other people during an IS process (e.g., higher confidence, greater productivity, social dependencies, more valuable results). Amershi & Morris (2008) provide support for this hypothesis with an extensive diary study in which they observed information workers regularly opting for shared search experiences despite their use of status quo technologies. These researchers additionally predict that the frequency of people engaging in collaborative searching will increase when better tools become available and widespread. Morris & Teevan (2010) also come to the conclusion that “there is real need and motivation from end-users for improved social features in search tools”.

Following this explanation of the motivation for collaborative IS activities, the chapter outlines the theoretical dimensions of collaborative IS by introducing different group types, configurations, and strategies. In addition, the design space of applications aimed at supporting these activities is presented, along with several examples of attempts to enhance collaborative IS through the application of reality-based methods.

However, Blandford & Attfield (2010) ask how many of these reality-based approaches have been developed without consideration of real user requirements, and how many have only been implemented as technical showcases propelled by technology rather than utility. Many of the design decisions for these systems have been made implicitly, without stating the trade-offs with physical practice or existing workflows, or their impact on the embodiment of actions. Blandford & Attfield (2010) go on to argue that there is a need for a better understanding of how group dynamics and the individual behavior of group members will change with the application of these new technologies. In the following chapters, these aspects will be at the core of the investigation.

Key Points

- IS is a complex and multi-faceted process and collaborative activities are an essential and integral part of it.
- Groups that seek collaboratively adopt different group types (*experts and consumers*, *information intermediaries*, *communities of practice*), configurations (*direction*, *strength*, *longevity*, *group size*), and strategies (*loosely*- and *tightly-coupled*).
- Approaches that attempt to enable collaborative IS must address several challenges depending on their classification in the design space (space/time).
- RBIs offer promising possibilities for co-located, collaborative IS, such as equal access to information, smooth transitions between individual and collaborative activities, and more balanced participation.
- However, to date the influence of RBIs on collaborative work (especially in IS) has not been sufficiently explored.

4 The Blended Library

"Without libraries what have we? We have no past and no future."

Ray Douglas Bradbury (American short story and novel writer, 1920 –)

Contents

In this chapter, the Blended Library[1] research project (Heilig et al. 2010) will be briefly introduced as the research context of this thesis. The primary objective of this project is the development of novel concepts to support IS and collaborative processes inside the physical libraries of the future. With the help of these concepts, library visitors are able to experience new methods of searching and knowledge transfer. The concepts are realized through the intensive application of innovative interactive devices and trendsetting visualizations that merge or "blend" real-world services with virtual library functions. Therefore, this project provides an appropriate research environment to answer the research question of this thesis.

[1] http://hci.uni-konstanz.de/BlendedLibrary (2011-05-16)

4.1 Challenges of the Library of the Future

In recent decades, as a result of the ongoing digitalization and unlimited dissemination of information via the World Wide Web and digital libraries, physical libraries have lost their monopoly as knowledge providers. In contrast to physical libraries, digital libraries offer an almost infinite amount of digital content (e.g., e-books or e-journals) in combination with various digital functions, such as full-text search, sorting, and filtering. Furthermore, this information can be accessed anytime and anywhere.

On the other hand, physical libraries offer advantages that digital libraries cannot. The library as location of media items does not simply represent a static storing place; in addition, it provides a physical knowledge organization. This organization implicitly represents an information unit that reveals context information and draws various meaningful relationships between media items. Library visitors instinctively develop the ability to gather such "meta-information", which McCullough calls "spatial literacy" (McCulough 2005). Examples of information that is perceived and processed include the design and usage-related wear of book covers and spines, the number and appearance of other library visitors in a certain library area, the position of a shelf according to typical library organization or central library spots, and the position and surroundings of individual media items. In addition, some library visitors use the facilities of libraries not only for IS, but also to take advantage of the aura of silence and concentration needed for their work.

The library as a central place to meet, work, and learn conjointly or collaboratively represents another important aspect. Kuhlthau defines a person who intervenes in the search process of another person as a "mediator" (Kuhlthau 2004). This intervention includes assistance in accessing, locating, and identifying information items, as well as advice and constructive debate on certain topics, as can take place in students' group work, for example. People have distinct characteristics, which are referred to as "individual differences" (Borgman 2003). These factors can vary in terms of experience, educational level, personal interests, cultural factors, ethnic background, and affective stages. In contrast to commonly used digital library systems, a human mediator (e.g. a librarian) can recognize these factors in context and is therefore able to react appropriately to these individual differences, by presenting selected information items in a way that can be understood, or by helping to locate information items that would be useful in a certain situation. Abowd et al. (1999) describe this situation: "When humans talk with humans, they are able to use implicit situational information, or context, to increase the conversational bandwidth."

Another reason to visit physical libraries is the presence of "real" media items on the shelves. Many important resources are not yet digitally available; however, even for those that have been digitized, real media items as physical artifacts provide numerous characteristics that cannot be projected into the digital world (Sellen & Harper 2002). For example, real books permit a natural reading experience that addresses more than the purely visual information provided by e-books. Via skimming and quick scanning of books, readers are able to rapidly construct a mental model of their content. Several research studies have also detected the so-called "serendipity" effect (Foster & Ford 2003) that directs readers during the skimming and scanning process to new ideas and perspectives.

There have been attempts to project these physical and social characteristics of real-world libraries onto digital libraries. The digital visualization of book covers and the integration of social meta-information via "social tagging" have already been successfully integrated in several digital services. However, applications that attempt to transfer the social, spatial, and tangible characteristics of a real-world library into digital libraries – such as chat functions or digital representations of physical architecture – have not yet found their way into many productive digital systems.

Furthermore, in the majority of cases, digital libraries are limited to one single user tied to a physical workstation with keyboard and mouse. The user's social and physical contexts are not considered; nor are his or her individual skills. However, these factors are essential in order to profit from the user's characteristics and experiences during the process of IS. As a result, many users perceive digital libraries solely as passive warehouses (Adams & Blandford 2005).

The Blended Library research project aims to develop concepts for the library of the future as one approach to solving the problems of digital libraries mentioned above. Thereby, the diversity, flexibility, naturalness, and tangibility of real work environments should be preserved and capitalized upon, in contrast to the disembodied and arbitrary "anytime and anywhere" (McCullough 2005) use of virtual objects and services.

In place of the co-existence of physical and digital libraries, a blending of the two should be established. This blend should merge the characteristics of real environments (e.g., the naturalness of interactions with books, paper, pens, and especially with other people) with the advantages of the virtual services of digital libraries (e.g., the ability to search huge digital catalogues, and the unconstrained dissemination and reproduction of electronic documents). To realize this vision, completely new methods of IS and knowledge transfer will be accessible to users through the application of new interactive devices, visualizations, and the integration of real-world objects.

The embodiment theory (Gibbs 2006, Wilson 2002, Chapter 2.1.4) constitutes the theoretical foundation for the design of the Blended Library and supports the necessity of a new generation of UIs. These interfaces serve library visitors by taking their location, social environment, and cognitive and physical skills into consideration – in contrast to current digital libraries that are generally accessed by an isolated user at a stationary workstation. We propose conceptual blending (Imaz & Benyon 2007) as an analytical tool for the realization of the Blended Library.

4.2 Conceptual Blending

This section describes the conceptual blending theory, which serves as a foundation for the Blended Library project. Human thinking processes treat abstract concepts in general metaphorically (Lakoff & Johnson 2003). The application of metaphors in common language usage clearly demonstrates this statement. For instance, complex situations are often described with metaphors, such as "to find a needle in a haystack" or "to hunt for a book". In the design of interactive systems, metaphors are also often utilized as an instrument to benefit from pre-existing user experiences. In some cases, this carries the risk of raising false expectations on the user side (Imaz & Benyon 2007). This problem, called "cross-domain mapping", is often triggered by a direct projection of structures and characteristics from one domain to another.

In addition to metaphor theory (Lakoff & Johnson 2003), there is also a superordinate concept that allows indirect projection, called "conceptual blending" or "conceptual integration" (Fauconnier & Turner 2003). Conceptual blending defines four "mental spaces" (Figure 16): two partially overlapping domains ("input spaces") that provide the input for the projection; one "generic space", composed of shared abstract structures from the two input spaces, which represents the foundation for the projection; and the "blended space" or "blend". This blend is artificially generated through the selective projection of single structures and characteristics from the two input spaces. Thereby, new structures and characteristics that did not originally exist in the input spaces can evolve. This phenomenon is called "emergent structure".

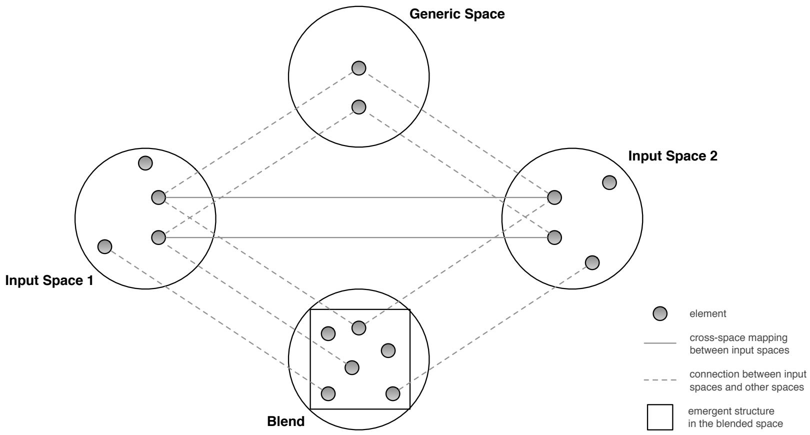


Figure 16 Schematic illustration of conceptual blending (Fauconnier & Turner 2003)

Despite its name, the “desktop metaphor” can be regarded as a typical example of a blend, according to Imaz & Benyon (2007). It consists of the two input spaces “computer commands” and “office work”, domains from which selected semantics and functionalities are projected in a new mental space – the blended space. Examples for the projection from the input spaces are “digital files” and “paper documents” or “digital containers” and “analog folders”. Shared abstract concepts from the generic space, such as the concept of “containers”, build the foundation for this projection. Users perceive the blend as a new and artificially created world in which they can build on their existing experiences and skills. Furthermore, new structures and functionalities can be integrated without awakening false expectations.

Blends can thus be used as conceptual tools for the design of interactive UIs (Imaz & Benyon 2007). Indeed, they do not implicitly result in understandable and intuitive UIs, but, according to Imaz & Benyon (2007), they could lead to new perspectives and ideas to support the requirements resulting from embodiment theory.

4.3 Case Study

In the following section, the concept of the Blended Library will be presented by a description of its first prototyped vision. This horizontal prototype is meant to be part of a case study, as defined by Lazar et al. (2010): “a case study is an in-depth study of a specific instance (or a small number of instances) within a specific real-life context.” We conducted this case study for several reasons: namely, to identify errors in reasoning, to observe the applicability of concepts, to gain new perspectives, to allow users to experience the vision of the Blended Library, and to integrate users into the development of concepts at a very early stage.

A subset of the Mediothek, the media library of the University of Konstanz[2] (consisting primarily of DVDs and VHS tapes), serves as the data set. These media items exist as physical items on the shelves of the library; however, they are also digitally available as meta-data and are (in part) fully digitalized. In addition, this data set is augmented by meta-data from various online sources and services, such as Google Maps[3] and the Internet Movie Database (IMDb).[4]

As an environment to simulate the library of the future, the "Media Room"[5] research laboratory of the Human-Computer Interaction group at the University of Konstanz was used in the case study. This laboratory offers a broad range of input and output modalities and is highly flexible in architecture, allowing adaptation of the environment to different scenarios. For example, the laboratory is equipped with several vertical and horizontal high-resolution display screens. Different input modalities can be utilized, including (multi-) touch, gestures, pens, and speech. In addition, typical artifacts of a library, such as shelves, books, and DVDs can be integrated to establish an appropriate simulation environment for the Blended Library.

The blends developed in the case study that will be described in the following section should be regarded as possible but not exclusive design variants to implement the idea of the Blended Library.

4.3.1 Scenario

With the help of a scenario, the detailed functionality of the case study as well as the implemented concepts of the Blended Library will be demonstrated. The scenario describes the case study by means of a realistic work process of university students. This work or IS process is based upon empirical and theoretical work from the research field of IS (Chapter 3.1) and covers a broad spectrum of activities, locations, and social contexts during an extended time period. The scenario will demonstrate how knowledge workers could be supported during their creative work process through deliberately created blends for interaction concepts.

[2] www.ub.uni-konstanz.de (2011-05-19)
[3] www.maps.google.com (2011-05-19)
[4] www.imdb.com (2011-05-19)
[5] http://hci.uni-konstanz.de/MediaRoom (2011-05-19)

Zoomable Object-oriented Information Landscape (ZOIL): Max, a Media Science student in his fifth semester, attends a seminar entitled "Fiction and Reality – Comic Adaptations in the 20th Century". During the seminar, the lecturer asks the students to write a term paper in groups of two on "Character Analysis of Main Roles in Real-World Produced Comic Adaptations"; the paper is to be finished by the end of the semester.

Directly after the seminar session, Max and the other seminar participants discuss the assignment topic, exchanging their first impressions. Max and Hanna agree to work on the term paper together. They immediately open Max's laptop and start the Blended Library application in order to get an overview of appropriate movies (Figure 17).

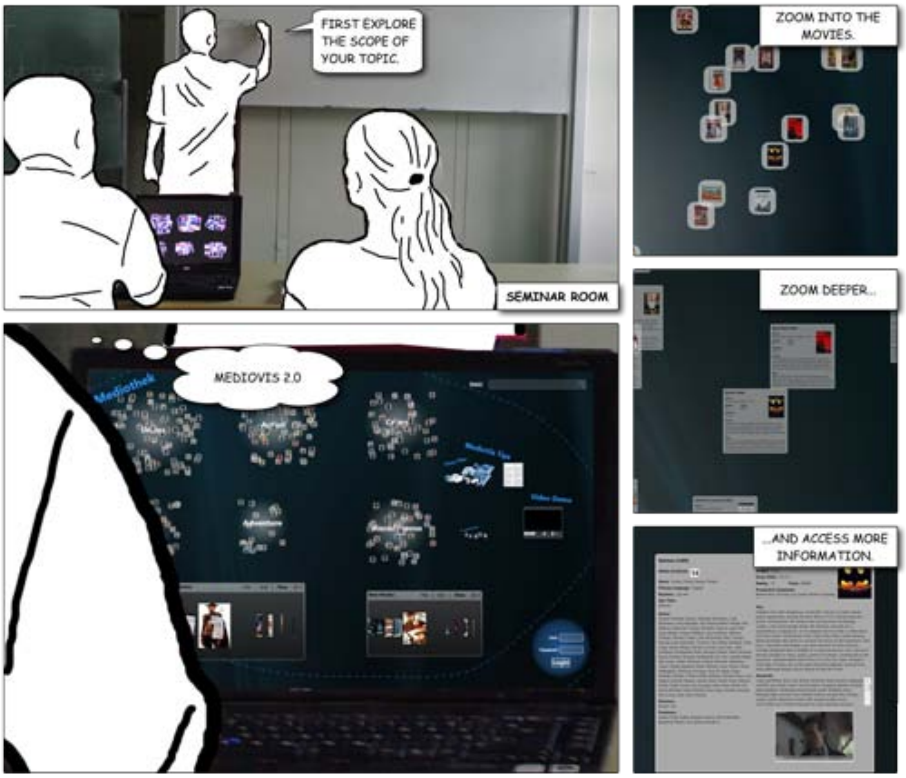


Figure 17 Blended Library Scenario: ZOIL
By means of ZOIL, it is possible to obtain an overview of the data set.

The visualization of media items in the case study is based on the fundamental blend *ZOIL* (Jetter et al. 2010b). This consciously created blend of the input spaces "navigation, orientation, and organization in physical spatiality" and "digital information space" serves as the foundation for further blends and concepts. *ZOIL* projects digital information as concrete objects on an information landscape of virtually infinite size, making use of well-known formats of arrangement and presentation borrowed from real life. Motion in the physical environment (moving towards or away from an object) is transferred into the zoom-based navigation.

This concept builds upon the work of Donelson (1978), who introduced the "Spatial Data Management System (SDMS)", a virtual canvas to visually access and spatially organize information objects. In addition, Jef Raskin's vision of "ZoomWorld" (2000) serves as an important source of inspiration. According to Raskin, zoomable UIs can be substitutes for browser-based and monolithic applications as well as traditional operating systems.

ZOIL serves as the basis for the visualization and provides the fundamental interaction model, which represents the starting point for the exploration of the information space (Figure 17). The system arranges each individual media item according to its genre in the information landscape. The cover image of the DVD or VHS tape is used as the default representation.

In order to provide visual landmarks, media items are placed onto halos (semi-transparent ovals) corresponding to their genres. The size of the halo is related to the number of media items in the genre. By the use of zooming and panning interactions, users can access arbitrary regions and media items presented in the information landscape. This navigation approach builds upon the human capability of visual and spatial orientation (Perlin & Fox 1993). To strengthen this perception, sinus-based accelerated animations are used that resemble movements in the real world. In addition, the information landscape includes a parallax-moving background, which is zoomed and panned by a smaller factor. This technique, often used in cartoons, improves the perception of spatial depth and is intended to simplify orientation within the landscape.

As consequence of the blend *ZOIL*, new structures, characteristics, and functionalities emerge that were unavailable in the input spaces. For example, it is now possible to explore the media collection through natural and intuitive operations. When a user zooms into the content of the landscape, more detailed information and functionalities (such as meta-data or processing functions) become accessible in subsequent representations, in accordance with the approach of semantic zooming (Perlin & Fox 1993). Available functionalities, such as playback of videos or access to a website, are bound not to isolated applications but directly to a corresponding information object, as proposed by the concept of object-oriented UIs (Collins 1995).

Search: Because Max and Hanna are still not sure of their choice of topic, they make an appointment with the seminar's tutor in the Mediothek. In this separate area of the library, the system is available on a public wall (Figure 18). Because of its size and interactive possibilities, it is conducive to group discussions. The tutor first starts a goal-directed search with search terms provided by Max and Hanna. He then offers advice on which movies might be appropriate to consider for their term paper.

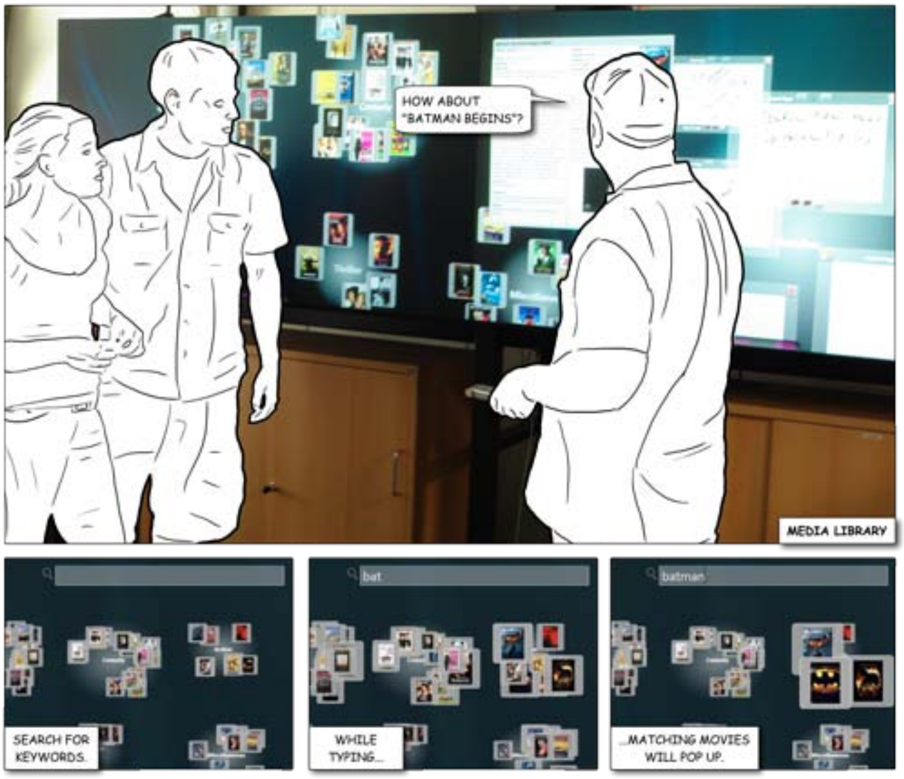


Figure 18 **Blended Library Scenario: Search**

A large high-resolution display as part of a public wall enables group discussions. Via a text-input field, relevant media items can be highlighted.

The system offers seamless integration of search functionality into the information landscape. No result lists or external windows are used to visualize the results. The input field in the upper right-hand corner of the screen (Figure 18, bottom) is the starting point for an analytical search in the case study. Every keypress results in the scaling of corresponding media items in the information landscape: the entered search term is compared with certain meta-data (title, year, genre, etc.) of the media items in the landscape. If a search term corresponds to a meta-datum, the matching objects on the landscape increase in size by a certain factor until they reach the maximum size, which is dependent on screen size. Noncorresponding media items decrease in size and opacity with the same factor until they reach the minimum size and opacity. By implementing this "dynamic query" (Ahlberg et al. 1992) and "sensitivity" (Tweedie et al. 1994) approach, the attention of the users is implicitly directed to media items that are currently of interest, without losing track of media items that do not completely match the search query.

This *search* functionality represents another blend, in which the input spaces are the two domains "searching information" and the previously defined blend *ZOIL*. According to Fauconnier & Turner (2003), blends can be structured hierarchically by using an established blend as one of the two input spaces. In this new blend, the semantic relevance of media items is projected onto the size of the objects in the information landscape.

Virtual Windows: At the end of the meeting, the tutor recommends to read the book "Structure and History of Comics: Contributions to Comic Research". Max searches directly at the public wall for the location of the book, before he resorts to the shelves in the library. There he finds the book in the organization section "Comic Literature". Subsequently, he starts to physically browse in direct proximity for further relevant media and discovers the manuscript of the movie "Road to Perdition". He opens the official Web site of the comic author via his *virtual window* (Figure 19) and thus gathers more information.

Besides the physical and well-known information discovering via browsing the shelves, the case study offer additional values through the seamless access of digital and multimedia information directly at the spot. Knowledge workers are able to explore these information spaces by means of a *virtual window* (Figure 19). *Virtual windows* are tablet-PCs that augment the visual scene behind the device with digital information and functionality. This way of digital enrichment of real-world views is called "Augmented Reality" (Rekimoto & Nagao 1995). Depending on the distance of the *virtual window* to the real objects, an optimized representation will be displayed. If a user for example focuses a whole shelf, the physical knowledge organization of the shelf (e.g. organization sections) will be visualized. However, if a single book is focused, a knowledge worker is able to immerge in the digital information space of this medium. By applying this technique, *virtual windows* provide an additional view that is complementary to the physical information space through digital information, such as comments, reviews or ratings from other users, access to encyclopedia articles, links to biographies, audio messages or podcasts, videos or even cross references to other media in the shelves of the library.

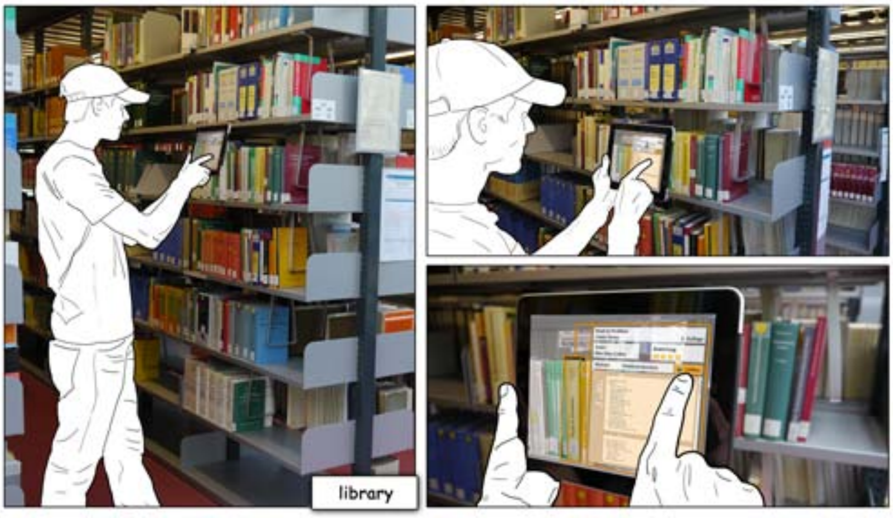


Figure 19 **Blended Library Scenario: Virtual Window**

The physical knowledge organization of libraries allows explorative browsing. Virtual windows enrich this freedom of physical exploration with an interactive access to complementary digital information.

Virtual windows are again the result of conceptual blending. This blend is constituted from the input domains of an optical lens and a digital display. The characteristic of a lens to focus specific objects and scenes is used to enable users access to before hidden information. The functionality of the digital display thus allows augmenting real scenes with virtual functions. By presenting the information directly on the spot, the physical context of the library (e.g. location, surrounding knowledge organization, peripheral media objects) will not be lost.

For the technological implementation[6], a tablet-PC is used that offers a physical form and integrated hardware and inherits thus optimal conditions for the blend *virtual windows*. The books in the shelves can be recognized as distinct media as well as their positions (rotation and translation) by means of the software-library ARToolKit[7], optical markers at the book spines and a conventional RGB-camera. The visual markers will then be digitally overprinted with visual and interactive elements on the screen of the Tablet-PC.

Portals: At home on his PC, Max searches for media items that directly relate to the chosen topic of their paper. He uses the concept of *portals*, an additional method of analytical exploration offered in the case study.

[6] The technological implementation of *virtual windows* was realized by the students Eike Kleiner and Benjamin Schäfer during the lecture Blendend Interaction in the winter term 2010.
[7] http://artoolkit.sourceforge.net/ (2011-07-14)

Through the selection of an arbitrary region of the information landscape with the help of a bounding box, users are able to generate a *portal* (Figure 20), which reveals a new view of the underlying objects (Perlin & Fox 1993). In these *portals*, various visualizations are provided that allow filtering as well as analysis and interpretation of data. In the case study, users are able to choose between three different interactive visualizations: a cover flow visualization, the two-dimensional scatter plot HyperScatter (Gerken et al. 2008), and the table-based visualization HyperGrid (Jetter et al. 2005).

In addition, *portals* provide visualization-independent filter mechanisms. These filters remain active even when the user changes the visualization inside of the *portal*. By moving and scaling the *portals* in the information landscape, the system allows a directly manipulative and visual mode of formulating complex search queries, similar to the magic lenses and tool glasses proposed by Bier et al. (1993).

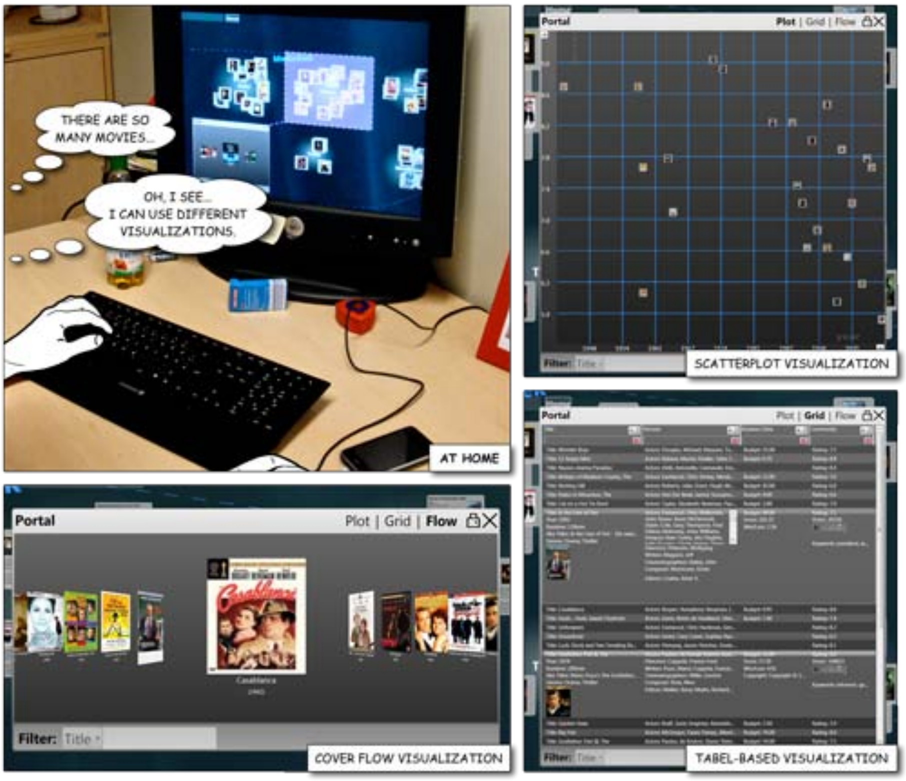


Figure 20 **Blended Library Scenario: Portals**

Portals offer an analytical tool to analyze the information space in detail. Users are thus able to explore subsets of the information space with various visualizations and can also apply visualization-independent filters.

Again, the *portals* in the case study are the result of conceptual blending. The blended space *portal* consists of two input spaces: the already established blend *ZOIL* and the familiar concept of an optical lens. Objects in the information landscape are projected into a *portal*, just as real-world objects are projected through an optical lens. As a result, new opportunities emerge that were not available in the individual input spaces. This emergent structure allows users to gain new perspectives on information objects by means of several visualizations or filters.

In addition, users can store the state of a *portal* via the lock icon, in order to preserve a *portal*'s visualizations and filters for later use. A previously developed search query is therefore not lost, but instead becomes a stable artifact in the IS process.

Annotation: With the help of *portals*, Max assembles further important media items for the term paper. Later, he watches these movies directly on his home television (Figure 21). As he watches the movies, he takes *annotations* on important facts and sketches ideas using the system.

Figure 21 **Blended Library Scenario: Annotations**

By means of a home cinema system, movies can be watched in one's living room. Annotations that are made with pen and paper during the movie are later digitally available in the system.

The blend *annotation* uses real pen-and-paper interactions, projecting this aspect into the information landscape of *ZOIL*. Knowledge workers are thus able to retain their personal procedural methods and can still use natural and intuitive handwritten records.

The foundation of the technical implementation of this blend is the Anoto technology.[8] Using an Anoto pen and special paper, it is possible to transfer handwritten or sketched records directly to a PC. The pen perceives its position on the paper by means of a distinct but nearly invisible dot pattern printed on every page. The records are broadcast to the system practically in real-time and are thus immediately digitally available. In this way, it is possible to organize and arrange *annotations* in a straightforward fashion within the information landscape.

Hybrid Medium: Throughout the rest of the semester, Max and Hanna regularly meet in the Mediothek to talk about the movies they have seen, to discuss ideas, and to concretely determine the focus of their work. They use the multi-touch table at the media library (Figure 22), where they collaboratively review their annotations and systematically search for missing information.

Social activities play an important role in several stages of IS processes (Kuhlthau 2004, Chapter 3.1). Therefore, the Blended Library provides the required space and promotes these activities with new approaches. Furthermore, the real media objects on the shelves of the library are essential during the IS process. One crucial task is the search for media objects that relate to the primary theme of the term paper.

In the case study, media items on the shelves can be used as TUI (Ishii & Ullmer 1997). In contrast to traditional interactions with mouse and keyboard, TUIs engage users to actively participate in the interaction. The users are able to interact with these TUIs as they do with real world objects, and are thus able to apply their previously developed skills and experiences. According to Ishii & Ullmer (1997), the application of TUIs is especially meaningful in the context of information management, processing, and manipulation; they propose the "blending" of physical objects with virtual functionalities in order to fully exploit the full potential of TUIs.

By placing a real medium (Figure 22, DVD) on the multi-touch table, the object will be recognized and assigned to the corresponding digital representation; this is similar to the concepts Beck & Schrader (2006) specifically developed for books. Within the case study,

[8] www.anoto.com (2011-05-23)

however, interactive control elements appear after a user places a physical media object on the table (Figure 22). By means of these controls, digital functionality (such as searching for similar media items) can be accessed.

Figure 22 **Blended Library Scenario: Hybrid Medium**

DVDs on the shelves of the library are integrated into the interaction. By placing a physical media object on the surface of an interactive table, it is recognized and interactive controls are provided (to search for similar media items, for example).

The blend *hybrid medium* is composed of the input space "real medium on the shelves of a library" together with the established blend *ZOIL*. The real media items are smoothly integrated through the generic and shared characteristic of object-orientation in the two input spaces. With the help of this new blend, new functionalities can be implemented, such as filtering the digital information space according to specific attribute occurrences of the real, physically present medium (e.g., certain actors, genres, or year of publication). The users are naturally supported during the exploration of the comprehensive media collection and the surrounding information space. In addition, this technique permits access to additional, previously hidden information and services, such as full-text search in movie scripts and ratings from other users.

4.3.2 Participatory Design

In order to integrate users into the design process, a qualitative user study was conducted at an early stage of the development of the case study.

The primary goal of this study was to evaluate the comprehension of the developed blends. Therefore, user understanding of the navigation, orientation, and content presentation concepts in the fundamental blend *ZOIL* were observed in particular. The blends *search* and *portals* with their filter concepts were also the objects of investigation. Special attention was directed to the integration of search results into the information landscape, where we expected problems of overlapping. Due to the early stage of the development, the blends *virtual windows*, *annotations* and *hybrid medium* were not part of the user study.

As a secondary goal of the user study, we analyzed the portability of the UI and interaction concepts on different devices. We also attempted to obtain insight into the quality of user experiences.

Participants and study design: The user study was carried out with 11 participants (7 female, 4 male), ranging in age from 21 to 27. The participants were students and teaching staff from the University of Konstanz in Law, Linguistics, Politics, and Economics. The participants were divided in two groups: One group (7 participants) performed the user study on a PC in a usability lab; the other group (4 participants) completed the study at a large, high-resolution display, simulating the public wall of the media library described in the scenario above.

The PC condition used a 21-inch TFT-display with a screen resolution of 1280x1024 controlled by a mouse and keyboard. A mouse click on a media object in the information landscape triggered an automatic zoom to the corresponding object. Alternatively, the users were able to zoom continuously using the mouse wheel and could pan with the middle mouse button. In contrast, the high-resolution display consisted of two seamless rear-projection screens with an aggregate resolution of 3840x1080 pixels (Figure 18). This setting was operated by an infrared laser-pointer (König et al. 2007), which allowed absolute pointing, in addition to a standard keyboard. To guarantee a fair comparison between the devices, the laser-pointer had buttons and a wheel similar to the mouse and therefore offered the same zooming and panning functionality as the PC condition.

Screen captures and video streaming from a camera that monitored the participants during the user study were gathered. An observer situated in the next room had live access to these streams and systematically took notes.

To reduce the influence of the experimenter on the results, the study was standardized and structured according to established principles. The user study was divided into three stages: (1) an introductory, exploratory stage that allowed the participants to freely interact with the system without biases. In this stage, the participants were asked to "think aloud". As soon as they felt confident in their interaction with the system, they were to describe their mental model of the system. (2) After this first stage, a video that demonstrated all sytem features was shown. Subsequently, the participants executed 15 given tasks with the prototype. At the end of this stage, the participants were asked to complete an AttrakDiff questionnaire (Hassenzahl et al. 2003) to determine the quality of the user experience. (3) In the third and final stage of the user study, we conducted an interview in which participants were asked both closed- and open-ended questions to validate the observed impressions.

Results: The qualitative results reported below are derived from observations of the participants' interactions as seen in the video material as well as from the participants' statements during the explorative, task, and interview stages of the user study.

ZOIL – The navigation of the information landscape with zooming and panning was generally considered positively, but during several tasks difficulties and comprehension problems occurred. All participants preferred a direct and automatic zoom per click for the navigation. The continuous zoom triggered by the mouse wheel was regarded as a supplementary alternative. Some participants detected this feature late or did not detect it at all. In the interviews, several participants remarked that initially the navigation did not match up to their expectations. According to the participants' statements, one factor that contributed to this perception was the zoom speed during the automated zoom triggered by a mouse click; this was regarded as being too fast.

Neither the basic layout nor the orientation of the information landscape caused any problems during the free exploration stage or during the task stage. The participants described the layout of the landscape as "clearly arranged" and "reasonable". In contrast, the visualization of individual media objects created certain problems. Some participants stated that the information was presented in a way that was too "unstructured". During the interviews, demand emerged for better organization of the presentation of information inside a media object, possibly via separation of different aspects of interest in visually divided regions.

Search – All participants understood the blend *search* immediately in the exploration stage; however, the user study uncovered several problems. During the tasks, four participants complained about overlapping result objects and the consequent resulting lack of overview. Two participants explicitly addressed this issue in the interview session. In addition, a textual list previewing results directly at the search input field was requested, which contradicts the idea of a seamless integration of results into the information landscape. One participant additionally asked for visualization of the search results inside a new *portal* in which filter mechanisms could be executed.

Portals – In the exploration stage, only four participants took notice of the blend *portals* and the connected visualizations. However, after watching the introduction video, all participants were able to solve the tasks with the help of *portals* without difficulties. During the interview sessions, *portals* were described as "comprehensible" and "reasonable" by several participants. The concept of "magic lenses" was also understood and applied without errors after participants viewed the introduction video. In contrast, *portal* storing and locking remained unclear for some participants. According to the interviews, the reason for this issue was the inappropriate icon that was not recognized and interpreted in the intended way.

Different devices – Although the two groups executed the user study on different devices, they demonstrated very similar reactions. No differences could be detected in comprehension of the concepts. Handling of the system using mouse and keyboard was immediately accepted. In contrast, handling via laser pointer was at first new and unfamiliar for the participants. However, after a short training session during the exploration stage, participants had no difficulties working on the tasks using the laser device.

User Experience – An additional goal of the study was to gain insight into the user experience of the system. An AttrakDiff single evaluation was conducted (this evaluation can only show tendencies, due to the small number of participants). We also explicitly asked questions concerning the hedonic quality and visual design during the interview sessions. The participants assessed the visual design of the system as "very attractive" and "convincing". These results correspond to the results obtained from the AttrakDiff evaluation. In terms of the hedonic qualities (HQ) "attractiveness", "identity", and "stimulation", the system is situated far above the average. The pragmatic qualities (PQ) achieved average values. This corresponds again to the outcome of the tasks and interviews, which identified opportunities for improvement in terms of the usability of the system.

Discussion of results: In summary, the developed blends in this case study are generally appropriate for the implementation of a Blended Library. This is true to a great extent even for the hierarchically structured blends *search* and *portals*. The blend *search* was comprehended very well, but as expected the overlapping of results must be resolved.

For the further development of the system, the input spaces as well as the presentation of blends should be deliberately selected. This issue emerged as an essential factor in the ease of learning for the blends. The *search* blend was detected and comprehended immediately during the exploration stage; in contrast, most of the participants did not encounter the concept of *portals* until after they had seen the introduction video. Furthermore, it was determined that details such as the zoom speed or the organization of meta-data inside a movie object are important to understanding the system and its interaction model. This first explorative and qualitative user study showed the power of conceptual blending as a conceptual tool during the design process.

4.4 Related Work

Several approaches from HCI, such as Ubiquitous Computing and tangible UIs, promise to bridge the gap between physical and digital media repositories. Fitzmaurice (1993) introduced already a “Computer-Augmented Library”, an idea that draws on these approaches in the context of physical libraries. In his vision the shelves of a library are connected with an electronic database. The shelves and books communicate orientation data and semantic information to mobile devices of the library visitors. In addition, the shelves are interactive via touch-sensitive LCD-rows and thus users are able to select and search directly on the spot. In 1999, Weiser presented another idea to facilitate the use of physically available media by means of digital technologies. The index cards of a library should be used as navigation device, to guide library visitors to a sought-after medium in the shelves.

Furthermore, emerging information and communication technologies in various physical dimensions, ranging from mobile devices over multi touch tabletops to large high-resolution wall displays or interactive advertising pillars, disclose new possibilities for future knowledge work. The research project “SmartLibrary” (Aittola et al. 2003) demonstrates for example how library visitors may reasonable use their mobile devices. Thus, PDAs were applied as navigation devices in the physical library and after an evaluation study even adopted into the real environment of the university library of Oulo, Finland.

Besides the introduced ideas, Rekimoto & Nagao (1995) described a technique to link the real media of a library with the digital world. A mobile device, called “NaviCam”, shows a video of the visible scene and recognized color-coded IDs in the real environment. Supplementary, expedient information such as additional information to the books in the shelves is overlaid in the video scene.

Figure 23 Tangible Books and Transformation Lab

(a) Tangible Books: Virtual library interfaces (Beck & Schrader 2006);
(b) Transformation Lab (Schulz et al. 2007).

Recent research efforts to enrich the library as physical location with virtual functions were introduced with "SearchLight" by Butz et al. (2004). A result of a digital search is thus visible in the real environment through a projected spot light. Optical markers and a camera recognize the media and a steerable projector at the ceiling illuminates the sought-after media in a shelf. A further approach, called "Tangible Books" (Beck & Schrader 2006, Figure 23a), recognized books and the open pages on a tabletop system through a camera and RFID-chips. This information is then used to offer access to corresponding virtual media.

The project "Transformation Lab" (Schulz et al. 2007) used the foyer of the public library of Aarhus, Denmark over a period of three years, to develop a variety of interactive installations for the library of the future and to observe their effect in a real environment of a library. One of these interactive exhibits was an interactive floor, on which the library visitors were able to leave SMS messages (Figure 23b).

Despite of the described related work, the potential of innovative ideas in this research area is far away from being exploited. Particularly the interplay of the mentioned and still to be developed technologies and concepts promises further valuable possibilities for the library of the future. Weiser described this effect as following: "The real power of the concept comes not from any one of these devices – it emerges from the interaction of all of them".

To apply these concepts reasonable in a real library, new and integrative interaction and visualization techniques are essential. This could be one reason that until now the introduced concepts are only sporadically integrated in the real environments of libraries. Furthermore, a lot of approaches haven't approved their applicability under real conditions. For this purpose it is necessary to analyze the technical integration into the existing infrastructure of a library as well as the conceptual integration into the habits and processes of library users. The concepts and technologies should not serve as an end in itself, but support the library users in important activities of knowledge work in a natural manner.

4.5 Outlook and Future Work

Emphasis in the further development of the case study will be increasingly placed on reality-based UIs. The blend *hybrid medium*, described in the scenario by means of a DVD, enables new methods of knowledge transfer that should be enhanced and refined with new blends in the future. In addition, other challenges of knowledge work in libraries must be faced, such as the generation of new knowledge artifacts and the integration of extensive information spaces.

Figure 24 **Mobile Devices in the Blended Library**

Mobile devices are becoming increasingly influential in the information-seeking processes of knowledge workers. Therefore, future concepts will address this aspect.

In addition, the interaction concept of the system should be reconsidered in terms of portability to additional devices used by knowledge workers during their IS processes. One example is mobile devices, which offer many new interaction possibilities (Figure 24). In addition to the use as independent client applications, the devices themselves can be integrated into the interaction, in combination with multi-touch tables or interactive surfaces similar to the *hybrid medium* blend. In this way, a new design space can be generated that offers nearly infinite possibilities: for example, magic lenses on an interactive surface with the help of the mobile device's display, remote control interaction, or the use of mobile devices as "intelligent" TUIs.

Figure 25 Interactive Reading Environment

During the reading process, continuative information is visible on a large peripheral display. This approach allows users to follow literature references, to clarify open questions or to activate new thoughts.

To process and make sense of information constitutes another important part of the Blended Library. Reading and the accompanying reflection are central aspects of these activities. New devices, such as E-Book reader or tablet-PCs play an essential role for this task in the library of the future. The process of understanding for example a research paper relies to an essential extent on sensemaking. For instance, making relations to other work or linking it to information gathered previously. If such functionality or information is not instantly available, the gap needs to be bridged by the knowledge worker (e.g., search and browse in the web). However, access to external resources interrupts the reader from his main task – reading – especially if reading comprehension is regarded as an essential task, which is performed better if it is done with no distraction.

Therefore, the concept of an "Interactive Reading Environment" (Figure 25) supports knowledge workers with in-depth details on a document and information related to it by offering these contents on an additional ambient wall-sized display. The system searches implicitly for related information, while the user continues reading. This information is then displayed dynamically and unobtrusively on the ambient display. A study from André et al. (2009) has shown that "personalization scores correlate with both relevance and also with interestingness, suggesting that information about personal interests and behavior may be used to support serendipity". Therefore, this display may encourage the knowledge worker to explore the personalized information space on demand and to offer the chance for serendipitous discoveries.

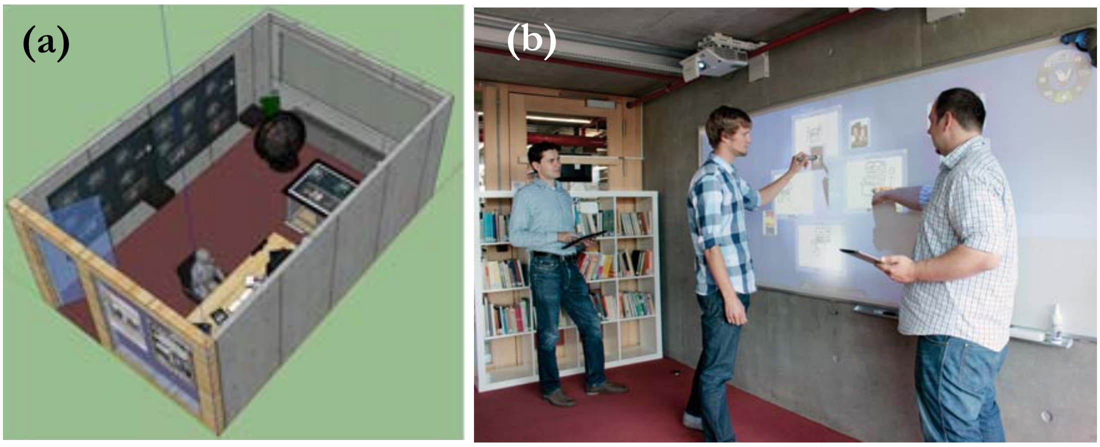


Figure 26 Blended Library Living Lab

(a) 3d sketch of the Blended Library living lab that is integrated in the environment of the library of the University of Konstanz (b) Three colleagues working in front of the public wall.

Besides the Media Room, a further lab is under construction that is integrated in the physical and social environment of the library of the University of Konstanz (Figure 26). Thus, we are able to use this environment in accordance with the idea of a "living lab" (Følstad 2008) for the development and seamless evaluation of new concepts and methods of interaction. Følstad defines living labs as "environments for innovation and development where users are exposed to new ICT [information and communication technology] solutions in (semi)realistic contexts, as part of medium- or long-term studies targeting evaluation of new ICT solutions and discovery of innovation opportunities". The technical and conceptual integration of such a ubiquitous environment can thus be evaluated and demonstrated, without being recognized as research lab from the library visitors. Via this living lab, the applicability and sustainability of the Blended Library vision can be observed.

4.6 Chapter Summary

In this chapter, the concept of the Blended Library was introduced as the research context of this thesis. In the "library of the future", the experiences, skills, individual processes, and changing physical contexts of knowledge workers will be important factors for consideration. With the inclusion of human characteristics, interactions between the system and knowledge workers can reach new levels. Embodiment theory demonstrates why it is important to consider cognitive, social, and physical characteristics in a balanced fashion when designing interactive systems. As a method of supporting the requirements of embodiment theory, conceptual blending is used; this method promises to promote the creativity of designers during the design process of interactive systems and to broaden their perspectives.

The concept of the Blended Library was showcased by the prototyped system. For the UI, the blends *ZOIL*, *search*, *virtual windows*, *portals*, *annotations*, and *hybrid medium* were developed to enable knowledge workers to use not only their cognitive skills, but also their physical and social skills and real-life experiences during their interactions with the system. This was presented with the help of a realistic scenario based on the insights of the IS models described in chapter 3.1. The scenario depicts situations in which users work on different activities using various devices at different places and in changing social environments. Users are thus able to accomplish their work within one consistent interaction model. Special attention was paid to the physical library as a place to meet and to learn in collaboration with others. A first qualitative user study during the design process demonstrated the basic comprehension of the introduced blends. In summary, with the Blended Library we developed an appropriate research environment for reality-based UIs that aim at supporting IS activities. Hence, we can implement our concepts and design cases for the topic of investigation of this thesis into this vision. Furthermore, it offers enormous promise for additional research activities regarding the integration of emerging technologies in the real-world practices of information seekers.

Key Points

- The Blended Library research project constitutes the context for this thesis.
- Based on the embodiment theory, conceptual blending has been selected as the conceptual tool to be used for the development of UIs for the Blended Library.
- The case study presents a first prototype of the vision of the Blended Library.
- An explorative, qualitative user study demonstrated the general applicability of conceptual blending.

5 Design Cases

"Just as some displays are getting smaller, large displays with both projected views and touch-screen interaction will become cheaper and more prevalent. These will help facilitate collaborative information access as well as better support complex information analysis activities and visualization. Touch-screen displays may also change the dynamics of how people interact with search systems, and displays that project images onto tabletops or even into the air may enhance multi-person search efforts."

Marti Hearst (2009, Search User Interfaces, Chapter 12)

Contents

This chapter describes in detail three design cases that aim to support collaborative IS activities. These design cases were specifically developed taking into consideration the principles of RBI. The ideas for the design cases emerged from the vision of the Blended Library and can thus be seamlessly integrated into the scenario introduced in chapter 4. Each design case seeks to explore a different aspect of collaborative IS, e.g., various IS strategies from exploratory search to analytical search, as well as different group configurations and group types.

In each of the three design cases, a subset of the same motion picture database is used. The information objects provided in our design cases are enriched with data from multiple web services, including the IMDb, Google Maps, and Wikipedia as described in chapter 4.

The description of each design case is structured as followed: After a short statement of motivation, the key design decisions for each design case are presented, followed by more detailed descriptions. Through a deliberately chosen balance between computational power and the level of reality, the design cases showcase how digital search tools can be designed to facilitate group IS activities. The trade-offs each interface makes in this balance between “reality and power” (Jacob et al. 2008, Chapter 2.2.3) will be analyzed in the discussion of each design case.

5.1 Facet-Browsing

5.1.1 Motivation

The Facet-Browsing[9] design case has been developed to allow a group of users to browse or perform exploratory searches in an information space. This IS strategy is frequently used at the beginning of an IS process (Chapter 3.1.2). Dörk et al. (2011) noted that in this phase the challenge is generally "to design search interfaces that help information seekers gain and maintain a sense of orientation". Marchionini (1995) observed that "exploratory search is an attempt to broaden IS from simple lookup towards knowledge building", while White et al. (2006) characterized exploratory search as the strategy of users to "explore, overcome uncertainty, and learn".

Facet-Browsing

Setting:	multi-touch tabletop
Space:	co-located
Time:	synchronous
Group Conf.:	small groups (2-4)
Group Type:	experts and consumers, information interme-diaries
Task Type:	negotiate, choose
IS Strategy:	browsing
Work Style:	tightly-coupled

In addition, information seekers often consult domain experts (e.g., tutors, lecturers, healthcare professionals) or information intermediaries (e.g., librarians) in their quest to obtain an overview of a domain and to overcome uncertainty, especially at the beginning of an IS process. Therefore, Facet-Browsing seeks to support small asymmetric groups (experts and consumers, information intermediaries) working in a tightly-coupled style in a co-located and synchronous setting.

5.1.2 Design Decisions

As Dörk et al. (2011) stated, only a few techniques have been explicitly designed to support exploratory search; the approach of faceted navigation (Hearst 2009) is an outstanding exception. However, most implementations of faceted navigation are exclusively designed to support individual information seekers (e.g., Hearst 2009, Lee et al. 2009).

[9] Details of the technical implementation are published in Runge (2010). A video demonstration of Facet-Browsing is available on the attached DVD.

Facet-Browsing is an attempt to project the concept of faceted navigation onto a multi-touch tabletop in order to allow a group of users to collaboratively explore an information space. The key concepts and design decisions (specifically, the use of a *multi-touch tabletop* and *faceted navigation*) will be explained and briefly outlined in the following sections.

To confront the challenge of enabling multiple people to search for information simultaneously and collaboratively, several researchers have proposed the use of multi-touch tabletops (Chapter 3.2.5). The design of Facet-Browsing also relies on a multi-touch tabletop setting, as this option facilitates more natural interactions between users in such a way that awareness of the interactions, gestures, and posture of others during work and discussions is enhanced. Furthermore, interference and the thus resulting production blocking (Chapter 2.3.4) are also addressed by this design decision.

On the multi-touch tabletop, an interactive visualization inspired by faceted navigation (Hearst 2009) and zoomable UIs (Perlin & Fox 1993) allows multiple users to explore an information space. Through the application of concepts from faceted navigation, the visualization provides multiple approaches for the navigation of an information space without the need for explicit search queries. As a consequence, no text entry on a virtual keyboard is required, just as Morris et al. (2010) proposed with regard to IS systems on tabletops.

In addition, with the integration of faceted navigation concepts, the visualization attempts to reduce clutter on the shared tabletop display and promises to support the collaborative sense making that is considered by Morris et al. (2010) to be an integral part of the collaborative IS process. Faceted navigation approaches often realize these goals by the meaningful organization of results, by offering users multiple options to follow, and by providing previews of possible paths for navigation.

Yee et al. (2003) additionally observed that faceted navigation supports information seekers at the beginning of a search as they generate "ideas about what to search for". Similarly, a user study by Kules et al. (2009) determined that a faceted interface facilitates information seekers' orientation in an unfamiliar information space and offers "guidance for proceeding with their search".

The use of traditional classification methods (e.g., hierarchical classification) can trigger certain problems. Hearst (2009) described these classification methods as inflexible, since individual information items are assigned to one distinct category: to find an item, users are often forced to start their search with a particular category, even though they are unable to predict the category into which the sought-after information item has been classified. To resolve this problem with hierarchical classification, a system must repeat combinations of categories in order to allow users to find a specific information item by means of different category paths.

In contrast to hierarchical classification, faceted classification allows the assignment of multiple categories or facet labels to an individual information object. The difference between facet classification and other classification methods lies in the attempt to extract simple classes from a subset of documents and to subsume them into facets. Information items are thus "assigned to" multiple facet labels instead of being placed "into" a category system. Faceted classification can thus be seen as a method of labeling data or meta-data (i. e., of labeling the properties or attributes of information items). This method of classification is characterized by the grouping of individual attributes of an information item into orthogonal categories. Hearst (2009) consequently describes faceted navigation as the possibility to explore data from different perspectives. Facets can be considered superordinate concepts that characterize a categorized information space by the visible relevance of certain aspects and terminology.

Table 3 illustrates facet classification using the example of classification of motion picture data, such as the data used in the design case. In this example, "film location", "genre", and "language" cover typical facets that represent several facet labels or values. A movie can thus be found using a variety of single facets or combinations of facets; as a result, users are able to explore the information space and find information objects from different perspectives.

Table 3 Faceted meta-data of a movie object

Genre	Action	Drama	Thriller	
Language	English	German		
Film Location	San Diego, USA	Paris, France	London, Great Britain	Cancun, Mexico
Rating (0-10)	8			
…				

In several user studies, Hearst (2009) further described the characteristics of faceted navigation. They observed that faceted navigation helps to prevent the feeling of being lost in an information space: information seekers cannot end up with an empty results set, and the faceted navigation system implicitly communicates what kind of information items are in the collection. As a consequence, faceted navigation promises to be a suitable technique to allow seekers to gain an overview of a domain and to explore a large amount of data, even in collaborative situations.

5.1.3 Description of the Design Case

The information space used for this design case includes the meta-data of about 3,000 movie objects.[10] In the initial setup, the facet labels from the facet "genre" are visible as colored circles on the information landscape (Figure 27).

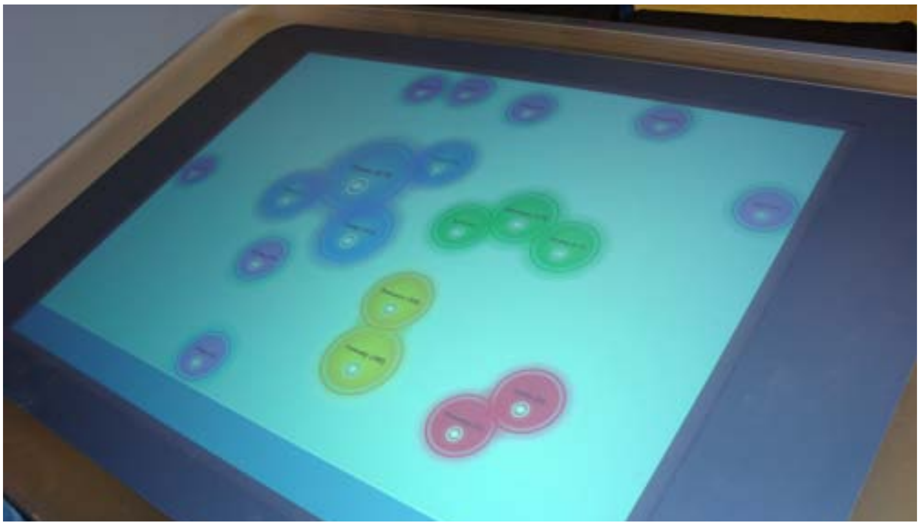


Figure 27 Facet-Browsing

The initial setup for the Facet-Browsing visualization. The facet labels of the facet "genre" are visualized using colored circles. The number of assigned information items is mapped onto the size of the circles, and the semantic relationships between the genres are mapped onto the position of the circles in the information landscape.

The colored circles are marked with their corresponding facet label (e.g., "action", "comedy") and with the number of information items that are assigned to the genre. These facet circles represent containers for their assigned information items, which are not directly visible on the information landscape in the initial setting. The size of these circles is linearly scaled, corresponding to the number of assigned information items. This representation is intended to allow collaborators to quickly gain an overview of the information space though the direct perception of meaningful facets.

[10] Randomly selected and extracted from the IMDb (Internet Movie Database).

Semantic Arrangement: A further characteristic of this initial visualization is the semantic arrangement of the facet circles on the information landscape. Related genres are positioned in direct proximity; unrelated genres are positioned at a greater distances.

The identification of semantic relationships between genres is based on the numerous user-generated IMDb keywords in the meta-data of the movie objects. All keywords were extracted from the data set and assigned to their corresponding genres in a genre-keyword matrix. In this way, the frequency of the occurrence of a keyword in a genre can be determined. Assuming that genres that share frequent keywords are more closely related, it becomes possible to compute similarities between genres. If, for example, the keyword "crash" appears very frequently in the two genres "action" and "drama", this could be used as an indicator for their similarity. As a consequence, it is possible to compute the cosine-similarity between two genres by means of their feature vectors, which can be extracted from the genre-keyword matrix. However, the high dimensionality of the feature vectors resulting from the large number of keywords creates difficulties. A reduction in dimensions was accomplished by means of a "Latent Semantic Analysis" (LSA, Deerwester et al. 1990), which preserves the meaningful dimensions and discards the remaining dimensions. To apply the result to the arrangement of the genre facets on the information landscape, a spring layout algorithm was utilized. This force-based algorithm was developed to visualize undirected graphs and is thus appropriate for computation of the positions of genre facets using the feature vectors extracted by the LSA. To increase a user's intuitive comprehension of the genre relationships, genre facets that appear in direct proximity form clusters that are represented with the same color. Information seekers can use this additional visual information as an orientation aid.

By means of the semantic arrangement described above, information seekers are able to detect similar or related genres and can thus choose alternative entry points. The arrangement is aimed at supporting orientation and overview using the facet circles as visual landmarks; with this initial setup, the UI should be perceived as offering simple and clear entry points to a complex information space.

Filtering through Zooming: Using the zoomable facet circles, information seekers have the opportunity to narrow down the information space according to their information needs. When a seeker taps a facet circle, an animated semantic zoom is triggered (Figure 28). In this way, the result set is pared down to the information items assigned to the selected genre.

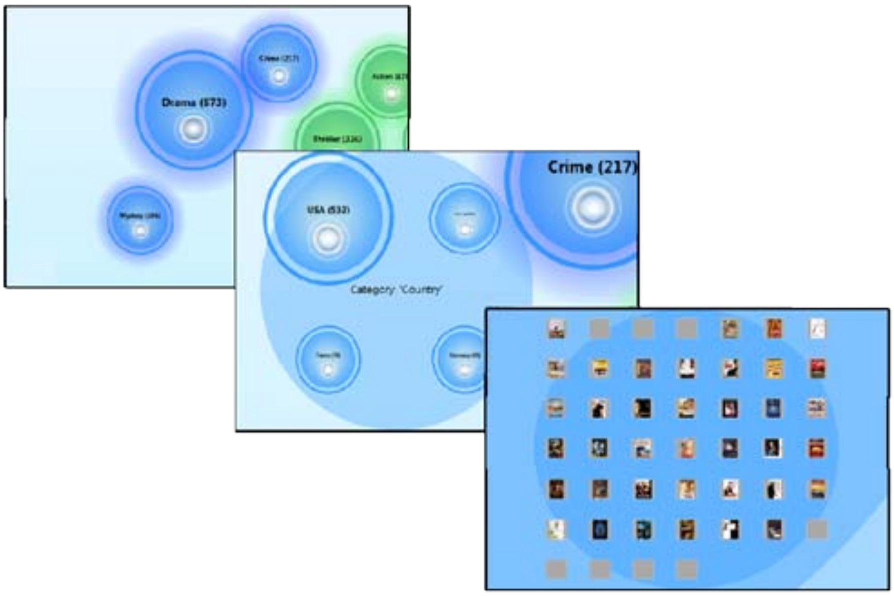


Figure 28 **Facet-Browsing Zoom**

A touch interaction on a facet circle triggers a semantic zoom. The result set is thus pared down to the information items assigned to the selected facet label, and a new (predefined) facet becomes visible. This filter action can be repeated until the threshold for visualizing individual information items is reached.

After the zoom animation, if the selected facet circle reaches a defined size threshold, the representation of the circle changes. A second facet (in a predefined order) fans out into newly visible facet circles that are logically and visually grounded within the initial genre facet circle. These new facet circles have the same appearance and functionality as the initial genre facet circles. The information seekers are again able to filter the results with the facet circles provided by simply tapping them. Tapping triggers a semantic zoom that fans out new facet circles, which information seekers can again use to narrow the result set, and so on. Throughout the entire filtering process, even in deep zoom situations, the color-coding of the facet circles remains constant to facilitate orientation for all group members.

Through the application of several filter steps via facet circles (such as the selection of a genre, a movie location, and a rating), information seekers are able to quickly narrow a large data set using only a few touch interactions. Figure 28 shows the course of action to find movies that are assigned to the genre "drama" and have a film location in "the USA".

During filtering actions, individual information items are invisible until the result set is narrowed to a number of items that would allow an easily comprehensible visualization (Hearst 2009, Figure 28). The threshold of the result set for the visualization of information items has been set at 50 items, a limit identified over several sessions as the value that ensures accessibility and ease of overview. However, in Facet-Browsing, information items are arranged in a simple grid. If other visualization methods (e.g., a scatter plot) were implemented, this threshold would have no validity.

The grid visualization of the result set provides further access to detailed information: a tap on a movie object triggers a semantic zoom; the enlarged view of the object displays the meta-data of the movie, as described in the Blended Library scenario (Chapter 4).

Pivoting: In addition the predefined sequence of facets, Facet-Browsing offers information seekers the possibility of selecting their own path of facets to narrow down a result set. This idea of changing the facet at any point in the exploration is inspired by the concept of "pivoting" (Lee et al. 2009). The pivoting technique allows information seekers to take control of the exploration process without losing the current context.

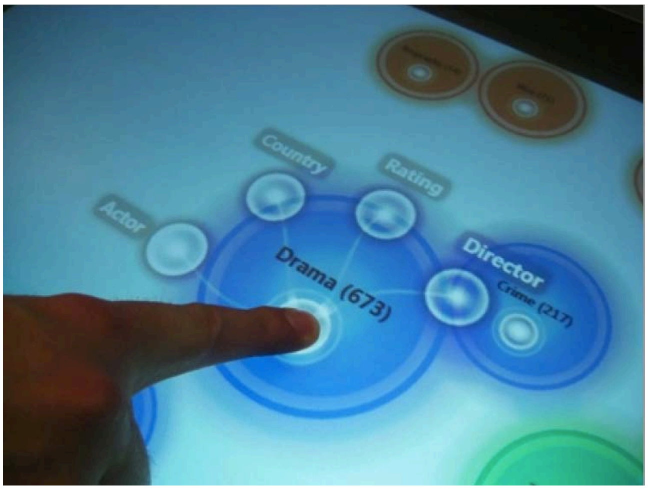


Figure 29 **Facet-Browsing Flower Menu**

Via a flower menu, information seekers are able to select their own filtering path through the information space.

To realize this feature, each facet circle contains a flower menu (Bailly et al. 2008) that can be accessed by touching the gray inner circle (Figure 29). This flower menu offers selection of the next facet out of all possible facets to filter the result set. Information seekers can thus choose the next filter step simply by selecting a branch of the flower menu with a finger gesture. This method of selecting menu entries was determined by Bailly et al. (2008) to be more efficient than linear menus. In particular, when users know the position of a menu entry (in frequently used menus, for example), they are able to perform the finger gesture without having to devote visual attention to the flower menu. This additionally enables all group members to follow the selection via the visible execution of an explicit gesture. Selecting a facet using the flower menu also triggers a semantic zoom, as described above for the predefined filter path.

Breadcrumb navigation: Another goal of the design of Facet-Browsing is to support awareness of orientation among all group members. Information seekers or collaborators should not lose their orientation during the IS activity; they should be able to recognize in every situation where the group is currently searching inside the information space. To this end, Facet-Browsing always provides a visible breadcrumb navigation bar (Hudson 2004, Figure 30) at the bottom of the interface.

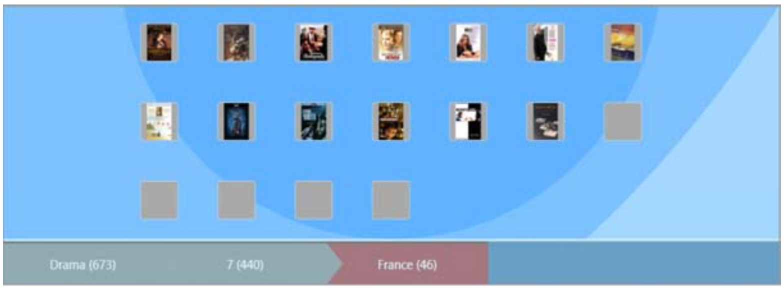


Figure 30 **Facet-Browsing Breadcrumb Navigation**

A breadcrumb menu at the bottom of the interface provides orientation for all group members.

In general, breadcrumb navigation is defined as the textual representation of the navigation path that a user has followed in an information space (Hudson 2004). The purpose of this concept is to provide users continuous feedback on their current position in the information space (Lida et al. 2003). Several user studies have found that breadcrumbs are an appropriate technique for maintaining as well as resuming orientation, resulting in better system usability (Hudson 2004). Today, breadcrumb navigation is utilized on the Internet to ensure orientation in complex website structures. In addition to this application, the breadcrumb technique has also become popular in systems that handle large and complex information spaces (e.g., Microsoft Pivot[11]). Breadcrumb navigation can be used to visualize various aspects of the navigation or the information space, such as “location”, “look-ahead”, “path”, or “attributes”.

The breadcrumb navigation implemented in Facet-Browsing concentrates on communicating the current facet path that the information seekers have followed (Figure 30). On every triggered semantic zoom, the breadcrumb bar is updated with a new facet label. All filter

[11] http://www.microsoft.com/silverlight/pivotviewer/ (2011-07-26)

steps show the number of items available at that position; the most recently executed filter step is highlighted. As a result, group members can reconstruct the previous filter actions. Furthermore, touching a facet label in the breadcrumb bar invokes the filter actions of the path up until the selected filter step by applying a zooming animation. In this process, the filter steps after the selected position are lost.

Figure 30 demonstrates a typical breadcrumb path in Facet-Browsing: all movies that are assigned to the genre "drama", that have an exact IMDB-rating of "7" and that are (at least in part) produced in the France. The visualized filter path reduced the result set from all information items (after the first filter step) to 46 information items (after the last step).

5.1.4 Discussion and Conclusion

The design of Facet-Browsing intentionally draws on several of the themes introduced by Klemmer et al. (2006, Chapter 2.2.2).

The co-located setting of information seekers around a shared tabletop display complies with Kelmmer et al.'s theme of *visibility*. In particular, the aspect of situated learning, which is an essential part of working in an asymmetric group situation (e.g., expert and consumers), is appropriately addressed by the setting used in Facet-Browsing. Collaborators are thus able to learn by participating in the IS activity, either through direct or peripheral participation. This results in a better affordance of group members and promises to facilitate collaborative IS.

In the theme *thinking through doing*, Klemmer et al. (2006) stated that "less constraining interaction styles are likely to help users think and communicate" because of the role of gesture in cognitive processes; Facet-Browsing facilitates this aspect with its alternative hardware setting lacking the traditional keyboard and mouse. The design case also addresses the factor of task representation mentioned by Klemmer et al. (2006). Facet-Browsing uses natural mappings, such as animated zooms and the metaphor of containers, to draw on information seekers' familiarity with the real world and to enhance task transparency.

In accordance with the characteristics of RBI (Jacob et al. 2008, Chapter 2.2.3), Facet-Browsing addresses several themes: naïve physics (NP) in the digital UI, as the zoomable UI mimics movements in the real world; body awareness and skills (BAS), by interactions that are directly executed by the hands of the users on the multi-touch tabletop; and environmental/social awareness and skills (EAS & SAS), through the physical setting of collaborators situated around a tabletop, which enables the use of known and real-world social conventions and communication behaviors.

Reality vs. Power Trade-offs: However, in the design of Facet-Browsing, several trade-offs between computational power and the degree of reality have been made.

Expressive power over reality – In several aspects, Facet-Browsing is designed in contradiction to the principles of reality in order to augment its expressive power. One example is the application of semantic zooming: changing the content of the visual representation of an object depending on the distance to the observer is a very "unnatural" behavior. However, this technique allows the construction of filter chains, and also reduces clutter on the display. Another example of inconsistency to the real world is the application of multiple instances or copies of information objects that are assigned to different facet labels. Using this technique, these information objects can be found and accessed under several facet labels, which is a central aspect of facet navigation and verifiably enhances the expressive power of Facet-Browsing.

Reality over efficiency – By applying an animated zooming approach, we intentionally favored reality over efficiency. Although a direct crossfade from one perspective to another would be far faster and thus more efficient, a zoom animation inspired by movements in the real world helps information seekers to keep track of the interactions made by the group and allows them to better follow the seeking context.

5.1.5 Conclusion

The design case of Facet-Browsing demonstrates the possibility of a deliberately designed reality-based UI to support exploratory or browsing-oriented search in asymmetric groups. Using the concepts of faceted navigation on a multi-touch tabletop, information seekers are able to explore an information space and gain an overview of it. The opportunity to examine an information space from different perspectives via the facets facilitates the information seekers' comprehensive understanding of the data. The translation of touch interactions into a faceted navigation approach in combination with zoomable UI elements establishes a simple and natural interaction that works without any keyboard input.

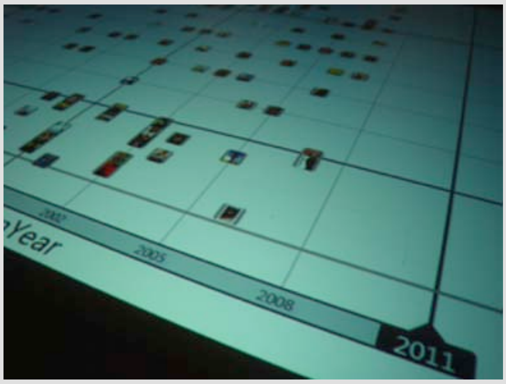
Because the zoomable UI gives collaborators only one focus and one navigation input at a time, the concept is indeed appropriate for asymmetric groups characterized by one person in a leading role. However, this technique is insufficient for communities of practice in which every participant plays an equal role. Consequently, the next design cases described in this chapter address concepts appropriate for symmetric groups.

5.2 ScatterTouch

5.2.1 Motivation

The ScatterTouch[12] design case (Heilig et al. 2010b) is a reality-based UI that allows a group of information seekers to accomplish IS activities such as comparing results, obtaining an overview of a joint set of results, and recognizing patterns. The design of ScatterTouch in support of these activities is based on the observations of Evans and Chi (2008) and Kuhlthau (2004) that exchange with other people plays an essential role during IS processes, particularly in finding the correct search terminology, in validating individual search results, and in communicating search results to other information seekers. In general, these activities are executed after the first steps of an IS process and include characteristics of both exploratory and analytical search. Examples of such collaborative IS situations include students working together on homework assignments, colleagues exploring the results of a user study, and families shopping a new home entertainment device. These groups are usually symmetric groups (communities of practice) in which every member acts in the same role.

ScatterTouch



Setting: multi-touch tabletop
Space: co-located
Time: synchronous
Group Conf.: small groups (2-4)
Group Type: community of practice, information interme-diaries
Task Type: negotiate, choose
IS Strategy: analytical search, browsing
Work Style: tightly-coupled

5.2.2 Design Decisions

As the design case focuses on the examination of search results, a *2D scatter plot* seems to be an appropriate tool to facilitate this activity. Ahlberg and Shneiderman (1994) observed that this visualization has advantages in analysis and in obtaining an overview of a heterogeneous information space. Through the spatial arrangement of data points mapped in two dimensions, users are able to identify relationships and dependencies in an information space. Furthermore, many implementations of scatter plots allow dynamic change in their

[12] Details of the technical implementation are published in Huber (2010). A video demonstration of ScatterTouch is available on the attached DVD.

dimensions that permits users to instantly attain new perspectives of the information space or of individual results without losing context. Researchers have developed a variety of techniques for the flexible and effective analysis of a result set using a scatter plot. The radical removal of data points using filter techniques (e.g., Ahlberg and Shneiderman 1994), zoomable scatter plots (e.g., Gerken et al. 2008), and fisheye scatter plots (e.g., Büring et al. 2006) are all examples of appropriate techniques to promote in-depth insight into a subset of data points without losing the context of the information space as a whole.

To allow a group of participants acting in equal roles to interact in a democratic manner while avoiding typical related problems (for example, when such a group works at one shared PC, problems could include troubles with contributing, lack of awareness, and referential difficulties; Chapter 3.2), we decided again to use a *multi-touch tabletop*.

In contrast to Facet-Browsing, which was designed to support asymmetric groups and thus offers only a single focus during the interaction, ScatterTouch must allow multiple information seekers to each define their own focus region (*multi-focus*).

In summary, ScatterTouch should facilitate a symmetric group of information seekers in the analysis of a joint result set in a natural manner. Thereby, the verbal and non-verbal communication of the collaborators should be executed in the real environment, while the interface should offer each information seeker an equal opportunity to engage in the activity. In addition, all collaborators should be able to follow and be aware of the interactions of the other group members.

5.2.3 Description of the Design Case

Based on the design decisions, ScatterTouch was realized as interactive scatter plot visualization on a multi-touch tabletop for the exploration and analysis of movie data in co-located collaboration situations. With the help of distortion techniques and natural gestures, it is possible to select multiple foci in the scatter plot.

Scatter Plot: In the basic setting of ScatterTouch (Figure 31), the data points are projected on a two-dimensional scatter plot. To demonstrate the concept of ScatterTouch, a subset (about 500 movies) of the movie data is used; consequently, the data points are initially represented by a visual thumbnail, and the scatter plot axes are initially assigned with the attributes "production year" and "rating". Labeling the scatter plot axes from multiple angles allows users to view and access the visualization from every side of the table. Via semi-circular buttons (Figure 31), one located on each table edge, a flower menu (Bailly et al. 2008) can be accessed. This menu allows users to change the assignment of the axes (e.g., from "production year" to "budget"), resulting in a smooth animation that repositions the movie objects on the scatter plot canvas. Awareness of the interaction steps executed by other group members is very important during collaborative work and is supported in ScatterTouch by extensive visual feedback, such as highlighted labels, grid lines, and regions, as well as by smooth animation.

Figure 31 **ScatterTouch**

Three co-located students using the ScatterTouch visualization on a multi-touch table. One student distorts the scatter plot grid to define a focus area for discussion. Two information objects are up-scaled to enable access to and comparison of the meta-information.

Fisheye-Distortion: The grid of the scatter plot has only a finite amount of space, and the data points often exhibit concentrations in clusters; to resolve this problem, ScatterTouch implements distortion techniques.

The distortion is based on a fisheye concept, similar to the method introduced by Büring et al. (2006). These researchers applied a fisheye distortion for a scatter plot visualization on small screens (such as PDAs), observing that users maintained an overview of and context for the data.

Through the sequential distortion of different regions of the scatter plot, it is possible to create a focus area offering sufficient space for exploration. Furthermore, this technique allows resolution of clusters of data points aggregated in certain regions of the scatter plot. In contrast to the method developed by Büring et al. (2006), ScatterTouch allows creation of multiple distortions in the scatterplot (Figure 32). Shoemaker & Gutwin (2007) observed the applicability of multi-focal fisheye distortions, reporting that multiple distortions were even more efficient and less error-prone than single distortions in certain situations.

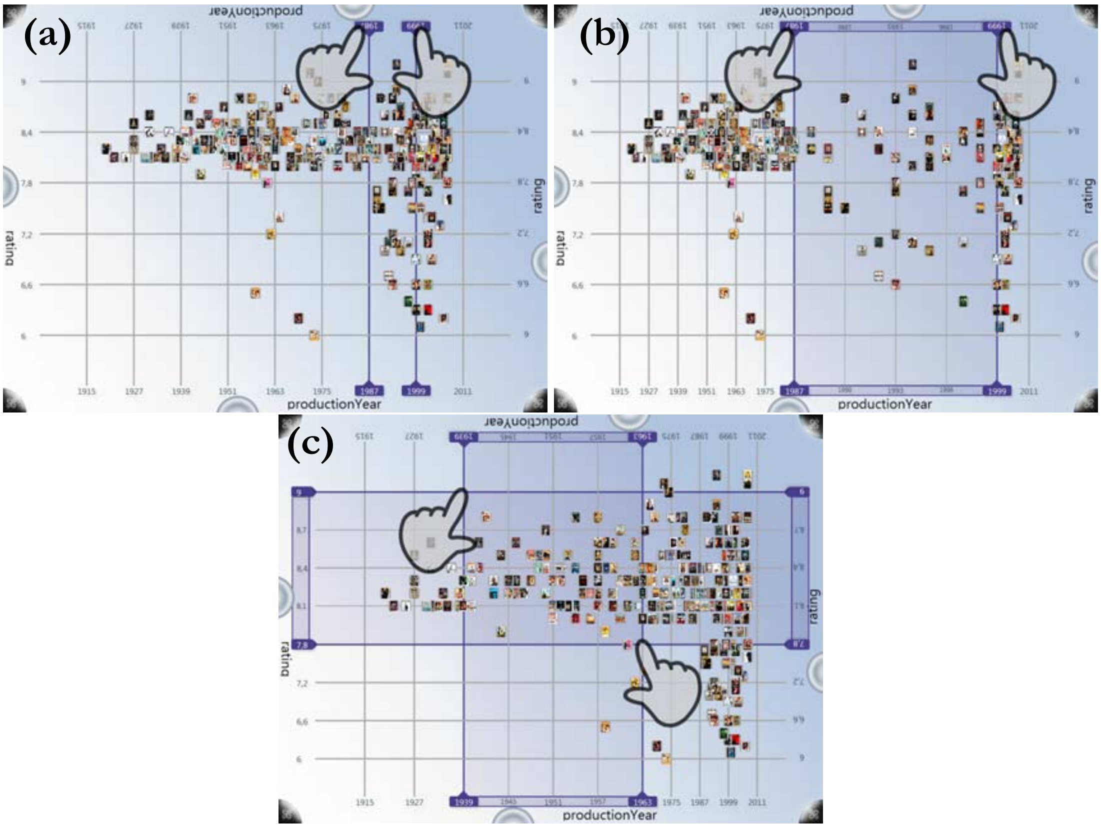


Figure 32 **ScatterTouch Distortion**

(a) Touching single or multiple labels or grid lines activates them for distortion; (b) Moving the activated lines results in a fisheye distortion; (c) A two-dimensional distortion can be established by dragging two cross-points of the scatter plot grid.

Rubber-Sheet Navigation: To enable users to naturally create focus regions inside the scatter plot visualization using the *fisheye distortion* technique, we utilize the rubber-sheet interaction concept (Sakar et al. 1993). Sarkar et al. (1993) introduced this technique to distort a vector-based map of the USA by mouse operations. However, instead of using a mouse, ScatterTouch enables users to stretch the grid of the scatter plot by simple finger gestures (Figure 32a, b, c), in analogy to a real-world rubber sheet.

By touching a grid line or label in ScatterTouch, the grid is activated for distortion. To manage finger precision issues and to guarantee accuracy, the grid lines and labels with the smallest distance to the finger contact are activated. Moving the activated grid lines via one- or two-handed spreading and pinching gestures results in distortion of the scatter plot. During this process, the activated grid lines are virtually connected with the fingers; the grid distortion develops as a smooth animation to help users keep track of the spatial arrangement of the movie objects (Bederson & Boltman 1999).

In this newly generated display space, it becomes possible to fade in new, more finely-grained grid lines and labels. The data objects in this focus region are now untangled, and users can explore them more precisely. As additional visual feedback, the distorted regions of the ScatterTouch interface are highlighted by a semi-transparent layer behind the objects (Figure 32b, c).

The grid distortion can either be accomplished in one dimension, by executing spreading and pinching gestures on the axis labels (Figure 32a, b), or in two dimensions, by executing such gestures inside the scatter plot grid (Figure 32c). Tapping on the highlighted area reverses the distortion, again animating the objects' reorganization.

With the help of this distortion technique, we offer a tool to define several focus regions inside the scatter plot grid. In this way, users can compare different regions in greater detail. In addition, the users have the possibility to define individual foci (Figure 33).

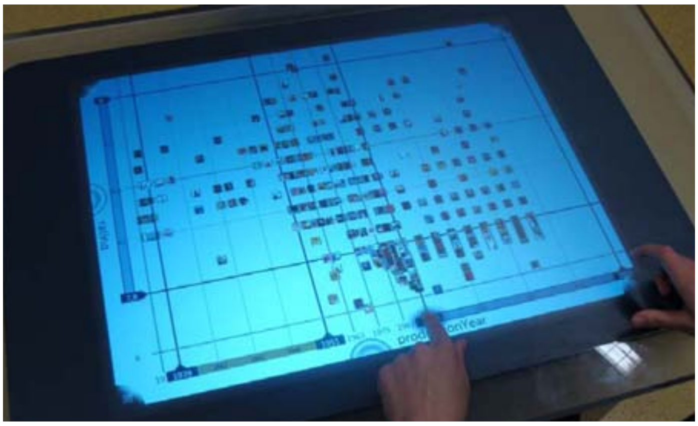


Figure 33 ScatterTouch Multiple Focus Regions

Multiple focus regions are defined to compare and discuss several aspects in a collaborative setting.

Details on Demand: To access detailed information for an individual object, a finger tap on the visual thumbnail triggers an animated up-scaling of the object, accompanied by a semantic zoom that reveals additional information (Figure 34).

Figure 34 ScatterTouch Detail View of Data Points

Tapping on a data point up-scales it; applying a semantic zoom, the meta-data of the movie is revealed.

The detail view is scaled according to the available space and is positioned around the center of the original data point; if this position is not possible due to the proximity of the data point to the borders of the visualization, the detail view is rearranged in one dimension in such a way that all information is visible. In this way, the users are able to reconstruct the position and mapped values even in the detail view. By "opening" the detail view of multiple movie objects, the group can compare the movies.

5.2.4 Discussion

The ScatterTouch design case also takes into account several themes from Klemmer et al. (2006). In addition to the unconstrained gestural freedom, as described in the case of Facet-Browsing, ScatterTouch allows the execution of "epistemic actions", which was identified as an additional aspect of the theme *thinking through doing*: through the playful manipulation of the scatter plot grid, information seekers are able to experience the information, which leads to a better understanding of the information. The theme *performance* is also addressed by allowing users to interact with direct, two-handed touch gestures.

With a special emphasis on the theme *visibility*, ScatterTouch facilitates the aspect of situated learning, as described in the Facet-Browsing design case. In addition, the visibility provided in the ScatterTouch design facilitates coordination in the community of practice, which is described as an essential aspect of supporting synchronous collaboration. The actions of collaborators are instantly visible to all group members, making it easier for group members to follow the actions of others and coordinate their own actions. This promises a reduction in coordination problems and consequently leads to a reduction in motivational problems of collaboration (Chapter 2.3.4).

ScatterTouch also explicitly incorporates themes of RBI (Jacob et al. 2008, Chapter 2.2.3): the applied distortion techniques are adapted from real-world interactions (NP), touch gestures are directly executed on the multi-touch tabletop display (BAS), and the physical setting (EAS & SAS) is familiar from real-world settings.

Reality vs. Power Trade-offs: Also in the design of ScatterTouch, several compromises concerning the degree of reality and computational power have been made.

Touch accuracy over reality – In interactions using a mouse, users are able to precisely point even at the pixel level; in contrast, touch interaction cannot achieve such accuracy. This is a consequence of the relatively large contact area of fingers that can cover a number of pixels, depending on the size and resolution of the display. In situations in which UI elements are smaller than the contact area or the elements are positioned in close proximity, it can be difficult for users to precisely hit the element. To guarantee that information seekers would be able to accurately select a grid line in the scatter plot, we decided to automatically choose the nearest grid line to the selected contact area's center. This contradicts interactions in the real world but empowers the users to directly distort the scatter plot's grid without repeating the touch interaction, as long as the correct grid line is selected.

Expressive power over reality – Another trade-off violating the principles of reality was suggested to enhance the expressive power of ScatterTouch. When distorting the scatter plot grid, the newly visible space is enriched with additional grid lines and axis labels to allow users to determine more precisely the position of the scatter plot's data points.

5.2.5 Conclusion

The ScatterTouch design case represents a reality-based UI that aims at facilitating exploratory and analytical IS activities in symmetric group situations. The concepts introduced in the design case enable communities of practice to compare results, to obtain an overview of an information space, and to recognize patterns in a joint result set. Through the application of distortion techniques in combination with touch-based rubber-sheet navigation, a group of information seekers can collaboratively explore an information space without the need for any keyboard input.

The current implementation of ScatterTouch is incapable of accommodating two users distorting the scatter plot grid in parallel, due to the fact that the multi-touch input is not assigned to a distinct person. If there are three or more touch contact points, the system is unable to decide between which two points the scatter plot canvas should be distorted. The group must instead define the multiple focus regions sequentially. The design of ScatterTouch, which promotes interaction and communication among group members, allows resolution of this problem through real-world coordination.

However, in more analytical IS activities, simultaneous interactions in a community of practice is an indispensable feature. The next design case will introduce an approach to address this challenge.

5.3 Search-Tokens

5.3.1 Motivation

The Search-Tokens[13] design case (Heilig et al. 2010c) has been developed to allow groups of users to execute the more analytical search activities that usually occur in the advanced steps of an IS process. One appropriate technique for implementation of an analytical search strategy in a collaborative setting is collaborative filtering Morris & Teevan (2010).

An example of this type of collaborative IS situation would be a group that has found its focus and is attempting to extract pertinent results from a larger result set. Like the target group for ScatterTouch, the groups using Search-Tokens are also symmetric groups (communities of practice).

Search-Tokens

Setting: multi-touch tabletop**,** tangible UI
Space: co-located
Time: synchronous
Group Conf.: small groups (2-4)
Group Type: community of practice, information interme-diaries
Task Type: negotiate, choose
IS Strategy: analytical search
Work Style: tightly-coupled

5.3.2 Design Decisions

The design case of Search-Tokens addresses several challenges presented by analytical search. Adams & Blandford (2010) observed that many IS systems assume that the users "are able to define the information they need in order to address a given problem", "know how to use a query language to formulate a corresponding query", and "are able to recognize the relevance of the result". Accordingly, we introduce a novel approach to analytical IS activities in collaborative settings with a lower entry threshold by considering a hybrid interactive surface.

Our design is based on a physical setting (Figure 35) that allows groups to engage in activities such as discussion and brainstorming in the real world. The design case includes the following components: a *multi-touch tabletop*, which is used as a control panel for collaborative IS and analytical tasks, and physical TUI components called *tokens* (Ishii & Ullmer 2007), which enable users to collaboratively formulate filter criteria.

[13] Details of the technical implementation are published in Demarmels (2010). A video demonstration of Search-Tokens is available on the attached DVD.

According to the literature, both TUIs (Hornecker 2002) and multi-touch technology are suitable means of supporting co-located collaboration. In contrast to mouse and keyboard systems, the two technologies allow multiple users to interact with a system simultaneously in a natural and intuitive manner.

5.3.3 Description of the Design Case

The design case of Search-Tokens uses the ZOIL visualization described in the Blended Library scenario (Chapter 4) for the visualization of results. This visualization presents about 200 movie objects on a zoomable information landscape beneath physical tokens. In the default view, the movie objects are displayed as poster representations. Semantic zooming is used to display three different levels of detail for each information object. Entering filter keywords by means of a Search-Token triggers a semantic zoom of the matching information objects. All objects can be freely arranged on the display using dragging operations. Users are thus able to create personal clusters of intermediate search results for discussion in the group.

Tokens: The basic concept of Search-Tokens are physical objects that can be placed on a multi-touch tabletop display as filter criteria (Figure 35). The hybrid interactive surface of Search-Tokens enhances the visibility of interactions with the system, since their physical appearance provides a more effective visual and tangible presence than a GUI based solely on digital sliders, text fields, or buttons.

Figure 35 **Search-Tokens**

Three co-located information seekers collaboratively filter a shared result set by means of Search-Tokens.

In contrast to approaches in which a tangible artifact acts as a physical representation of individual information artifacts, a Search-Token can be dynamically configured with a variety of search parameters, thereby acting as filter to the information space similar to Parameter Bars (Ullmer et al. 2003). The approach of Search-Tokens projects the construction of search queries onto physical rotary knobs located directly on the tabletop as on-screen controls (Weiss et al. 2009). When a Search-Token is placed on the tabletop, it is augmented by a visualization.

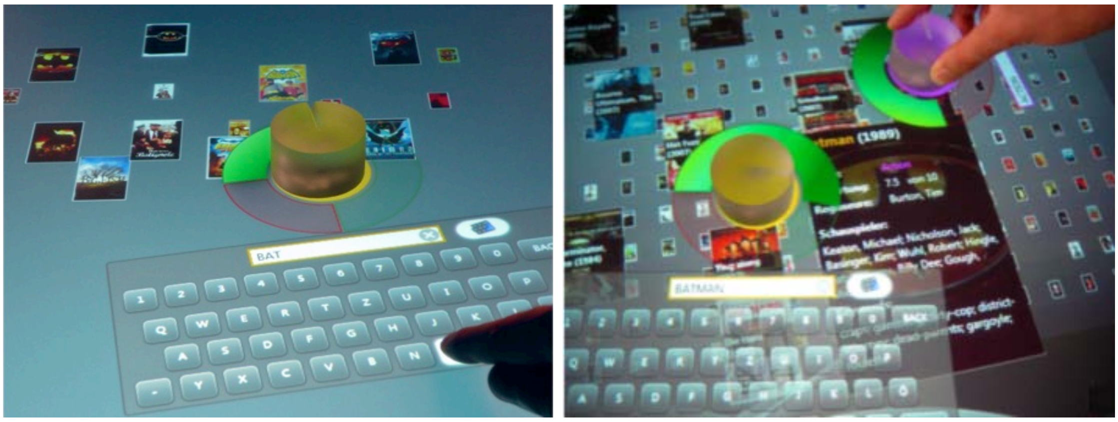


Figure 36 **Search-Tokens Query Formulation**

(a) A Search-Token as a hybrid surface on a multi-touch tabletop display enables users to simultaneously enter search criteria via on-screen keyboards; (b) By turning a Search-Token, the weight of a search criterion can be adjusted.

One Search-Token consists of four main parts (Figure 36): (1) a transparent Plexiglas cylinder (the physical object), (2) a textbox for filter keywords, (3) a circular indicator of the weight of the entered search criterion, and (4) a virtual on-screen keyboard. This keyboard can be temporarily hidden to save screen space. The visualization is virtually connected to the physical token like a "digital shadow", following its movement on the screen.

Moving and turning a token thus enables all participants around the tabletop to access the token's visualization. When a search criterion is entered, rotating the Search-Token allows users to define the criterion's weight. The circular indicator around the physical cylinder interactively shows the adjusted weight; the Plexiglas cylinder glows in the color corresponding to the criterion (Figure 36). To combine several search criteria, multiple Search-Tokens can be used on the surface of the tabletop display.

As our Search-Tokens are designed to perform sophisticated and analytical search tasks, each physically embodies a user-defined search term, enabling users to spatially organize multiple search terms on the table and allowing users to interact collaboratively with the information system.

Dynamic Query and Sensitivity: One important concept for Search-Tokens is based on dynamic filtering mechanisms; these mechanisms bring interesting information objects to the users' attention by means of keyword-based dynamic queries (Ahlberg & Shneiderman 1994). To support multiple users during collaborative work in a co-located environment, it is crucial that the actions of group members are traceable and comprehensible for everyone involved in the IS process. To address this issue, a filter method inspired by the concept of sensitivity (Tweedie et al. 1994) is used for our UI, instead of common filtering strategies that instantly hide all non-matching objects after filtering. To express that a specific information object matches a user-defined filter criterion, the visual representation of this object is enlarged, emphasizing its importance to all collaborators. With each key press, the movie objects on the information landscape that match the search term in one of their meta-data attributes (e.g., title, keywords, or characters) increase in size. The information objects that do not match the filter query decrease in size and increase in transparency, allowing users to easily visually distinguish between matching and non-matching information.

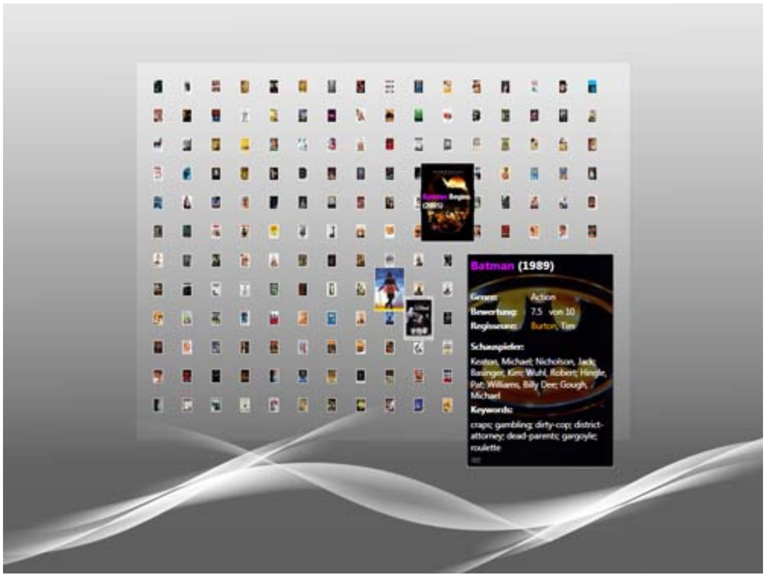


Figure 37 **Search-Tokens Result Visualization**

(a) The visualization with about 200 media objects; (b) Matching media objects increase in size and offer three semantic zoom levels representing different levels of detail.

Weighted Boolean Search: The combination of multiple filter criteria is a fundamental concept that enables each collaborator to personally engage in the search and exploration process. With the Search-Tokens approach, users can combine multiple filter criteria using Boolean operations. In accordance with the concept of sensitivity described above, information objects that match more than one filter criterion are represented as bigger than those that only match a single filter criterion. The default operation used to combine the different filter criteria is a Boolean AND. Additionally, users can interactively alter the weight of each filter criterion. This allows much more powerful search operations, and it can also enhance the collaborative process, in that a collaborator can scale the weight of a specific criterion up or down to better communicate corresponding aspects to other collaborators. The mathematical model behind the weighting of the filter criteria is based on the concept of weighted Boolean searches (Waller & Kraft 1979).

In addition, a color highlighting mechanism visually links matching information objects to the corresponding filter criterion (Figure 37). Each criterion has a distinct color, which is also used to highlight the matching keyword in the detailed information of objects. The colors in the result visualization can be used to associate information objects with the user manipulating the corresponding filter criterion, as proposed in collaborative brushing and linking (Isenberg & Fisher 2009).

Resize Algorithm: The resize algorithm (Figure 38) implemented in Search-Tokens is based on a simple mechanism: Each filter consists of a keyword and a weight. The keyword can either match or not match a specific information object (when it is found or not in the object's meta-data). The weight of each filter can be set between 0 and 2; this corresponds to the resize factor the filter will use to change the size of a matching information object. A weight between 0 and 1 will shrink all matching information objects, which corresponds to a (weighted) Boolean NOT operator; a weight between 1 and 2 will increase the size of all matching information objects. For example, a filter that matches a specific information object and has a weight of 0.1 would shrink this object to a tenth of its size, whereas a weight of 1.6 would increase the object's size by 60 percent. A growing and shrinking colored indicator around each Search-Token shows its weight and the corresponding filter criterion. The indicator glows green when the weight is larger than 1 (the filter increases the object's size) and red when it is smaller then 1 (the filter decreases the object's size).

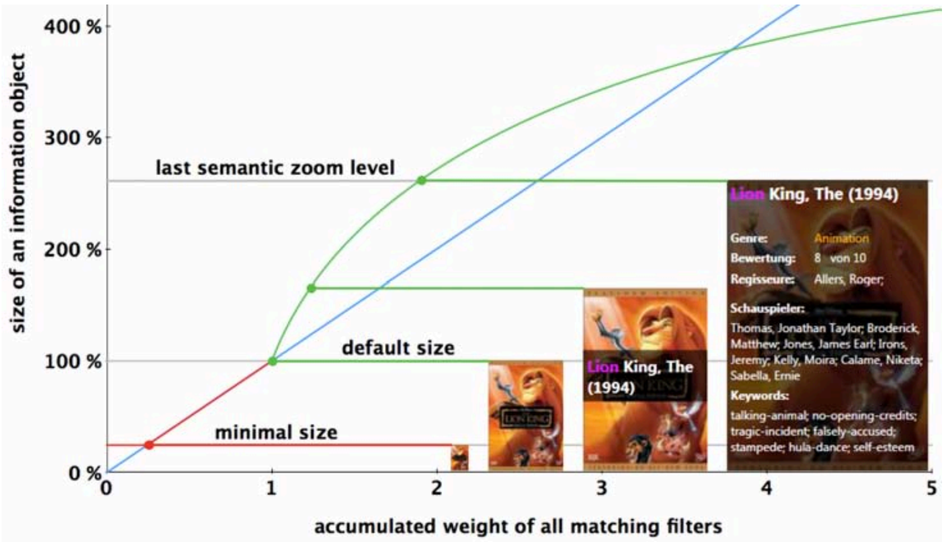


Figure 38 **Search-Tokens Resize Algorithm**

Schematic diagram of the resize algorithm for media objects: The linear function (blue) is altered by a logarithmic correction (green) to enhance an object's size.

The real size of an information object is calculated from all the weights of every matching filter. For example, if three different filters match an information object, one with a weight of 2, one with a weight of 1.5, and one with a weight of 0.8, the size of this object would be 2.4 (2 * 1.5 * 0.8 = 2.4) times its default size. This simple algorithm is modified by the application of a logarithmic function (Figure 38, green line) to help to resolve two separate problems: (1) Information objects that match a filter should get bigger even at low weights, so that more information details can be shown early in the process; (2) Once all detail information for an object is visible, the growth of this object should be restricted so that it does not occupy too much screen space and create clutter.

5.3.4 Discussion

The Search-Tokens approach addresses several of the themes of Klemmer et al. (2006) (Chapter 2.2.2), including body *performance* via the physical perception and manual manipulation of the physical tokens.

In addition to the aspect of the theme *thinking through doing* that suggests facilitation of unconfined gestural behavior (Klemmer et al. 2006), the design case also offers information seekers the possibility to execute "epistemic actions". By means of the physical manipulation of the tokens, information seekers can play through various configurations of queries. This "materialization of queries" (Jetter et al. 2010) also draws parallels to externalization of activity theory (Chapter 2.1.3). As previously described, the transfer of internal ideas into the physical environment and physical artifacts reduces cognitive load and thus frees up additional capacity for the actual task.

External artifacts are thus appropriate tools for communication in a group setting and address the theme of *visibility* introduced by Klemmer et al. (2006). Within a community of practice, information seekers can learn from one another and collaboratively enhance their domain expertise and seeking skills. Subsequently, due to the constant visibility of the physical Search-Tokens, all group members can follow and reproduce the actions of their collaborators, resulting in high awareness. This promotes better coordination of collaboration and thus reduces the motivational problems described in the section on process losses (Chapter 2.3.4).

Another theme of Klemmer et al. (2006) that is also deliberately invoked in the design of Search-Tokens is *risk*: interactions with a physical artifact cannot be exactly undone "while the consequences are not fully knowable". In the Search-Tokens design case, this aspect can be exploited to force groups to develop more trust through more committed engagement on the part of the collaborators. Because the consequences of an interaction with the system are immediately visible, information seekers may feel greater personal responsibility for their actions. Klemmer et al. (2006) argue that this "higher risk" may result in users paying closer attention to detail. The Search-Tokens design case therefore features a certain level of risk (e.g., in turning and positioning a Search-Token) that facilitates enhanced attention; at the same time, the design case tries to avoid high arousal by its clear and simple design. Otherwise, the combination of high arousal with high risk could lead to closed-minded behavior that is detrimental to collaboration.

Search-Tokens qualifies as a reality-based UI (Jacob et al. 2008), as it incorporates the main characteristics in a comprehensive manner: the physicality of people and objects (NP & BAS), the social context (SAS), and the environmental context (EAS).

Reality vs. Power Trade-offs: During the design of Search-Tokens, several trade-offs have deliberately been made.

Practicability over reality – Instead of using hardware keyboards with their haptic and sensible hardware buttons for the entry of search criteria – as, for example, in FourBySix Search (Hartmann et al. 2009, Chapter 3.2.5) – we decided to utilize virtual keyboards. Although this is inconsistent with the principles of reality, it offers several advantages. The virtual keyboard can be coupled to the physical Search-Token and thus freely arranged on the screen without much effort. In comparison to a physical keyboard, the virtual keyboard can be hidden when not in use and instantly restored when it is needed. This technique reduces clutter on the tabletop screen.

Reality over efficiency – Although it would be more efficient and more precise to enter the weight of a filter criterion as an absolute value (for example, via the virtual keyboard), we decided to allow information seekers to define weights exclusively by rotating the physical tokens. This decision for a more reality-based approach enables facilitation of collaborative processes, as described above.

5.3.5 Conclusion

Search-Tokens represents a reality-based UI that was developed to support symmetric groups (communities of practice) in analytical IS activities. The concepts introduced allow execution of collaborative filtering by means of physical artifacts on a tabletop display augmented by a tightly-coupled underlying result visualization. Because of the physicality of the tokens and the possibility of their simultaneous manipulation, the Search-Tokens promise to facilitate collaborative activities in a variety of aspects. For example, the high visibility of the Search-Tokens promoted by their strong physical presence enables collaborators to continuously perceive the current setting even from their different perspectives around the tabletop. Another advantage is the haptic feedback of the tokens, which allows interaction without forcing users to devote visual attention to the tokens. Overall, Search-Tokens introduces reality-based concepts that may have tremendous impact on the collaboration of information seekers. This design case has therefore been selected for use in two experimental user studies (Chapter 6) for the in-depth investigation of how group behavior changes with the use of reality-based UIs in comparison to other approaches.

5.4 Chapter Summary

The design cases introduced in this chapter are essential to addressing the research questions of this thesis. They intentionally span several dimensions of collaborative IS activities in order to obtain a complete picture of how reality-based UIs might enhance work practices. In the development of these design cases, special attention was paid to the trade-offs between reality and power.

As Blandford & Attfield (2010) noted is the enhancement of IS activities by new technologies only one side of the coin. Implementing new possibilities in existing processes and work practices may affect much more than simply the interactions with the system. This idea is also supported by the concept of “web of activity” described in activity theory: If one attribute (or corner of the web) is changed, other attributes of the activity must also be changed in order to renew stability (Chapter 2.1.3). Consequently, the experiments described in the next chapter sought to measure changes in group dynamics and behavior of individuals resulting from the use of reality-based UIs in order to obtain a more holistic view.

Key Points

- This chapter introduces three design cases to explore several dimensions of collaborative IS activities with a reality-based approach.
- Facet-Browsing is intended to support a tightly-coupled expert and consumer group by offering a browsing-oriented zoomable UI that allows exploration of an information space at the beginning of an IS process.
- ScatterTouch is designed to provide possibilities for a community of practice to investigate and analyze several search results in one consistent work space after the first steps of an IS process have taken place.
- Search-Tokens were developed as a tool to help communities of practice during the analytical task of filtering and refining results. These activities are generally carried out in the later stages of an IS process.
- When designing reality-based systems, it is crucial to analyze the trade-offs between reality and power (e.g., in the Search-Tokens design case, practicability vs. reality or efficiency vs. reality).

6 Experiments

"The strongest arguments prove nothing so long as the conclusions are not verified by experience. Experimental science is the queen of sciences and the goal of all speculation."

Roger Bacon (English philosopher and scientist, 1214 – 1292)

Contents

This thesis has discussed both pre-existing and new research that seeks to facilitate co-located collaborative IS activities by means of reality-based interfaces. In this chapter, the insights from previous sections will be further developed with the empirical support of experiments. In association with this thesis, two experimental user studies were conducted to evaluate various aspects of collaborative IS activities under changing interface conditions. However, in order to carry out user studies with reality-based UIs in collaborative settings, a number of challenges must first be acknowledged and addressed.

6.1 Challenges in Evaluating Collaborative Reality-Based UIs

According to Tang et al. (2010), it is essential in the design of effective new technology to pair it "with equally effective techniques for evaluating those techniques". However, as Jacob et al. (2008) observed, common evaluation techniques that are widely used for direct manipulation interfaces are not appropriate for evaluation of reality-based UIs. The following sections examine this observation in detail, highlighting aspects of standard techniques that should be reconsidered when focusing on the evaluation of reality-based UIs.

6.1.1 Data-Gathering Methods

In contrast to applications on a desktop PC, reality-based UIs often offer multiple (and sometimes even simultaneous) entry points or inputs. As a result, data-gathering techniques such as interaction logging must be carefully considered. When automatically logging interactions during a user study for a system that offers multiple inputs, the fact that inputs often cannot be attributed to a specific participant must be taken into account. For example, the touch contacts on a multi-touch tabletop display cannot be traced back to a specific user, as the system only recognizes uniform input contacts on a surface without any context information.

Tang et al. (2010) introduced an approach they called VisTACO to specifically address this issue. By using several multi-touch tabletops side-by-side to virtually shadow the interactions of each participant on the other tabletop displays, they were able to distinguish the interactions of each collaborator. However, this approach clearly interferes with the process of co-located collaboration and is thus not an appropriate technique for investigation of the research topic of this thesis.

Another example of a well-known data-gathering technique that is inappropriate for reality-based UIs is screen capturing (screen recording). Because interactions with many reality-based interfaces take place to a great extent in the real world (interactions with tangible objects, for example), simple screen capturing is insufficient for gathering data on these interactions. The social (verbal and non-verbal communication) and environmental (movement, change of visual focus) behaviors of participants are also very important aspects of reality-based UIs that are hard to capture. Furthermore, with desktop-based UIs, visual attention can be precisely determined with modern eye-tracking systems, as participants sit relatively motionless in front of a fixed-position screen; this aspect is much more difficult to measure when the real environment is part of the interface.

6.1.2 Performance Measures

Many researchers claim that reality-based interfaces offer significant benefits in addition to simple efficiency and effectiveness, particularly in group situations. Lindley & Monk (2008) argued that “the typical performance measures used in experiments (e.g., time to completion and the number of errors made) are no longer relevant”. However, the advantages of reality-based UIs – for example, intuitiveness (Jacob et al. 2008) and fluidity (Hornecker et al. 2008) – are the result of a loose combination of a variety of factors and are thus very difficult to measure. Even more problematic to measure are the often-cited influences of reality-based UIs in collaborative situations, such as awareness and interference (Lindley & Monk 2008), equitable participation (Rogers et al. 2009), different levels of participation (Marshall et al. 2008), and the level of trust within a group (Klemmer et al. 2006). A first attempt to measure the “quality of collaboration” was introduced by Burkhardt et al. (2009), in an approach that breaks down this quality into seven factors (including fluidity, mutual understanding, and information exchange for problem solving). However, measurement of these more specific factors is still complex and is based to a great extent on the design domain.

6.1.3 Impact

Although many researchers have argued that reality-based UIs can offer benefits beyond improvements in efficiency and result quality, some feel that “there is a paucity of empirical evidence or measures to support these claims” (Hornecker et al. 2008). Consequently, the standard parameters of efficiency and effectiveness are not the main focus of our user studies; the empirical research for this thesis instead emphasizes behavior patterns, interaction strategies, coordination mechanisms, and the roles that occur during group work in IS in order to investigate the professed advantages of reality-based UIs.

However, as described above, the evaluation of reality-based UIs in collaborative situations poses several challenges that demand a rethinking of standard evaluation techniques. For user studies with reality-based UIs, both Rogers et al. (2009) and Hornecker et al. (2008) have proposed qualitative analysis methods (such as video analysis) rather than purely quantitative data-gathering techniques (such as interaction logging) in order to obtain in-depth insights into participant behavior. Furthermore, according to Lindley et al. (2008) it is essential to identify “criteria to evaluate the ‘success’ of a sharable interface”, and to consider which aspects can realistically be measured.

6.2 Experiment 1: Simultaneous Interaction

6.2.1 Motivation

The first experiment (Heilig et al. 2010c) described in this thesis examines three different interface conditions using a multi-touch tabletop to detect influences on behavior patterns and effects on collaborative work. Particularly interesting in this study are the differences found between opposing design approaches – the physical Search-Tokens interface, with a very high degree of reality, the virtual Search-Wheels and a rather conventional input form – and the determination of which approach best facilitates collaborative filtering.

However, in measuring the quality of collaboration, a variety of factors that are hard to track in a single user study can play essential roles (Burkhardt et al. 2009). This study is therefore a first attempt to compare the quality of collaboration in the three different design approaches, with an emphasis on interaction behavior and especially on the simultaneous interaction of multiple participants. Moreover, observations and qualitative statements derived from the participants provide additional insights into how reality-based interfaces affect collaborative IS activities. The experiment attempts to answer the following two research questions:

- **Research Question 1 (RQ1):** Does the degree of reality affect interaction behavior, particularly the simultaneous interaction of a group in IS activities?
- **Research Question 2 (RQ2):** Which interface condition is the most appropriate tool to support collaborative IS activities?

A by-product of exploring these questions is that this first user study tests the methods of evaluation for reality-based UIs; the knowledge gained from this experience can be applied in subsequent experiments (Chapter 6.3).

6.2.2 Research Conditions

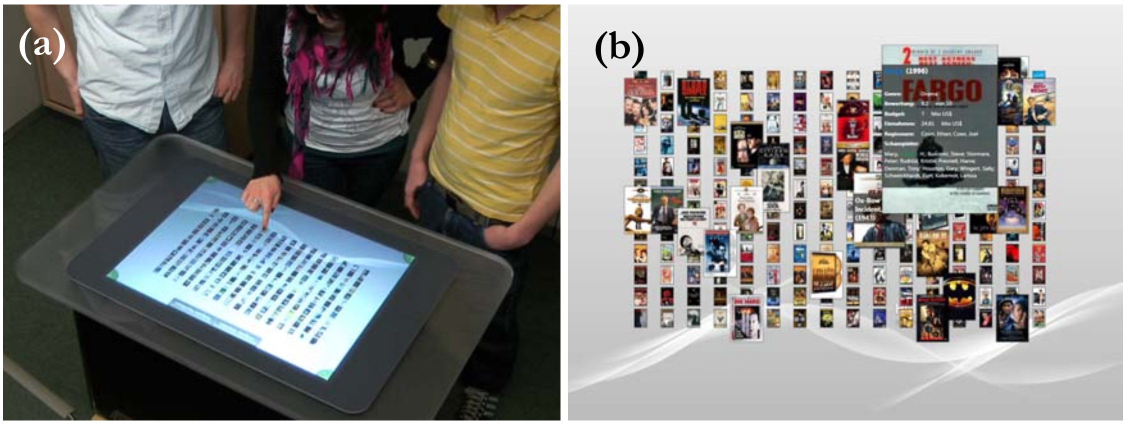


Figure 39 Experiment 1: Physical Set-Up and Result Visualization

(a) The multi-touch tabletop during the evaluation study with three co-located student participants. (b) When filter criteria are defined using one of the interface conditions, the relevant movie objects are up-scaled. Within this enlarged display space, the movie objects are able to show more information.

As previously described, multi-touch displays promise to enhance the quality of collaboration in various ways. The three research conditions in this study all used a multi-touch tabletop as a shared platform (Figure 39a). A special result visualization that arranged about 200 movie objects in a grid on the multi-touch tabletop display (Figure 39b) was developed for the analysis of the different interface conditions. To avoid any influence on the user study, the possibilities to interact with the visualization were deliberately reduced: users could not scale movie objects using direct touch gestures, but only via the interface conditions.

The next sections introduce the three different interfaces (Figure 40) for collaborative IS activities used as research conditions for the first user study: (a) the physical Search-Tokens interface, (b) the virtual Search-Wheels interface, and (c) a classic input form. All three implement the basic concepts of weighted Boolean search, sensitivity, and dynamic query, as introduced in the Search-Tokens design case (Chapter 5.3). Although they all use a multi-touch tabletop display, the interaction concepts behind the interfaces intentionally vary in the degree of reality. The purpose behind this design decision was to isolate specific characteristics of reality-based interfaces to enable analysis of their impact on collaborative IS activities.

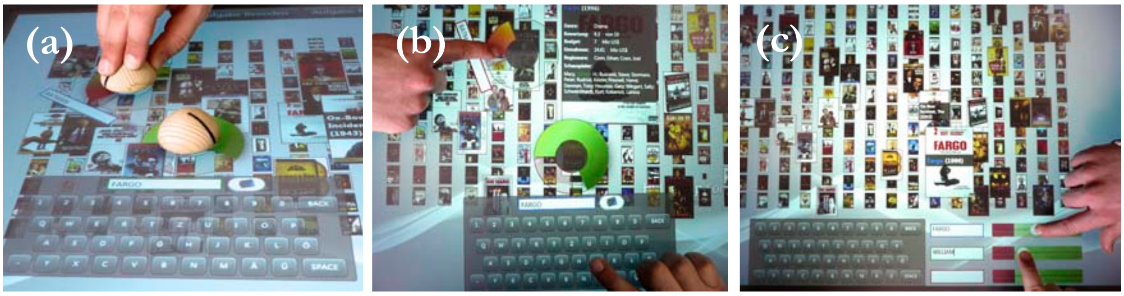


Figure 40 **Experiment 1: Research Conditions**

(a) Physical Search-Tokens; (b) virtual Search-Wheels; and (c) Classic Input Form.

Physical Search-Tokens: This interface condition (Figure 40a) is an early version of Search-Tokens (Chapter 5.3). All characteristics are the same as previously described, except that the Search-Tokens interface used in the experiment has a wooden rotary knob in place of the Plexiglas cylinder. As a consequence, no highlighting mechanism is implemented.

Virtual Search-Wheels: Search-Wheels (Figure 40b) translates the functionalities of Search-Tokens into a purely virtual interface on the multi-touch tabletop display. This system was developed in order to determine the differences between physical and virtual models of an interface.

By tapping on the marked corners of the tabletop display, virtual Search-Wheels can be generated. The appearance of this interface condition copies several elements of Search-Tokens: the text box to enter keywords, the circular weight indicator, and the virtual on-screen keyboard. Search-Wheels can be moved across the screen by a dragging gesture and rotated by a (two-finger) rotary gesture. When a Search-Wheel is moved beyond the boundaries of the tabletop screen, the wheel will be removed and the corresponding filters will be reset. A filter's weight can be adjusted by a finger gesture directly on the circular weight indicator (similar to the iPod's "click wheel").

Classic Input Form: The classic input form (Figure 40c) was developed with a deliberately conservative approach and a low degree of reality as a comparison condition to the two alternative interface conditions described above.

It consists of a single virtual keyboard, three input fields, and three associated touch-sensitive sliders. The three input fields correspond to the number of participants per group in the user study. When an input field is tapped, it becomes activated for text input from the virtual keyboard. In this way, the participants are able to define filter criteria for each input field.

The corresponding weight can be adjusted via the slider in direct proximity to each input field. As in the other interface conditions, these sliders can be manipulated simultaneously by multiple participants. The classic input form as a whole is positioned in a fixed position on the screen. However, the participants can change their physical positions around the table during the user study. To facilitate this behavior and to avoid the establishment of fixed positions, no chairs were provided to participants.

6.2.3 Participants and Design

18 participants with an average age of 23.5 (SD = 3.9) took part in the user study. The participants were students from various departments (excluding computer science); 56 percent were male. Before starting the tasks, subjects were asked to fill out a questionnaire about their prior knowledge of new media. The questionnaire results revealed that 89 percent of the participants had already had experience with touch-sensitive displays. However, only 50 percent of the participants had made use of TUIs to interact with a computer. The subjects were randomly distributed into three-person groups (triads), a typical size for small groups working together in IS (Chapter 3.2.2).

The six triads all worked with each of the three interface conditions (physical Search-Tokens, virtual Search-Wheels, and the classic input form). This within-subjects design was selected to facilitate comparison of the interface conditions. As a consequence, we used repeated measures for the statistical analysis. The sequence in which triads encountered the different interface conditions was completely balanced throughout the user study to prevent the influences of fatigue and inter-conditional effects.

Procedure and Tasks: After completing the questionnaire on prior knowledge of new media, the triads initially independently explored the functionalities of the multi-touch tabletop display and of their first interface condition. Systematic instruction was then provided by the experimenter to guarantee a consistent knowledge base across all triads before each interface condition. A training phase followed, implementing sample tasks to validate the participants' understanding of the instructions.

In the following phase of the user study, the triads worked on four tasks for each interface condition. The level of difficulty increased with every task, from relatively simple search tasks (e.g., "How many movies to which 'Spielberg' contributed are in the result set?") to rather complex tasks (e.g., "Which is the best-rated movie in the genre 'drama' to which people named 'Coen' contributed?"). In order to complete the tasks, the groups had to come to consensus decisions; they then entered their answer into a virtual input form on the tabletop display. After executing the first four tasks, a questionnaire regarding the interface condition was individually filled out by each participant. This procedure was repeated for the two remaining interface conditions.

After finishing the task phase of the user study, a final questionnaire that sought to compare various aspects of the interface conditions (e.g., how intuitive/tiring/collaboration-appropriate the interface conditions were) was distributed to the participants. At the end of the user study, the participants were asked open questions about the interface conditions and had the chance to discuss their experiences in a group interview.

The duration of the user study was between one and one and a half hours. Each participant received compensation of five Euro.

Analysis Method: Data from the user study was collected using both the questionnaires described above and video observation, as proposed by Rogers et al. (2009) and Hornecker et al. (2008).

After the user study, three observers simultaneously analyzed the videotaped interactions of the triads in one observation session. Each observer monitored one participant from a group. In analyzing the video data, the observers decided whether a participant had interacted with the UI or not during a five-second interval marked out by a metronome. The number of interactions was divided by the number of five-second intervals to obtain comparable results despite the variation in the task-accomplishing times of the triads (Figure 41).

6.2.4 Results

In the following section, we first describe the results of the video analysis, namely, the behavior patterns of the triads that emerged under the different interface conditions. Thereafter, the results of the questionnaires illustrating the subjective evaluation of the interface conditions from the participants' perspectives will be discussed.

Simultaneous Interaction (RQ1): Figure 41 demonstrates that participants took advantage of the opportunity to interact simultaneously with the Search-Tokens and Search-Wheels interface conditions.

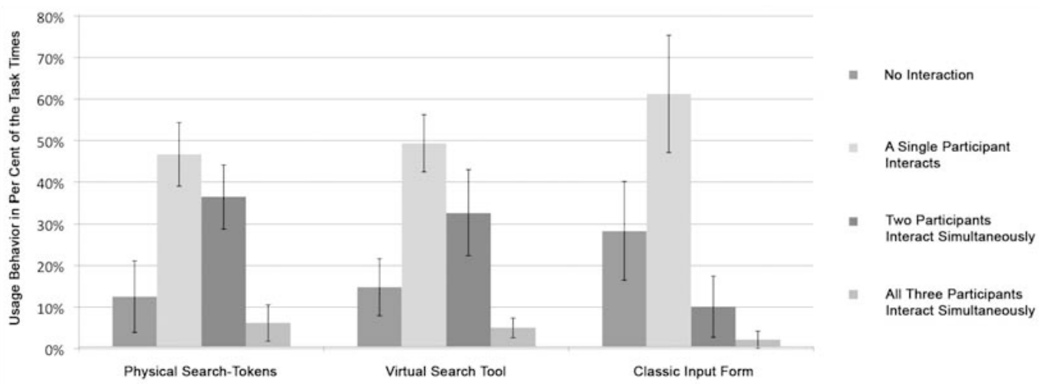


Figure 41 Experiment 1: Usage Behavior of the Triads

Usage behavior of the triads in the different interface conditions with interaction time during the tasks in percent.

In the classic search form interface condition, participants interacted in parallel only 10 percent of the time; this behavior was found 32 percent of the time in the virtual Search-Wheels condition and 36 percent of the time in the physical Search-Tokens condition. The simultaneous interaction of all three subjects was observed only very rarely in any of the three conditions, while interaction by only one person was observed most often: 61 percent of the time in the classic input condition, in comparison to 49 percent for Search-Wheels and 46 percent for Search-Tokens.

Appropriate for collaborative IS activities (RQ2): The subjective answers from the questionnaires drew a very similar picture. On average, the participants perceived the interaction with the classic input form to be the least appropriate tool for collaborative IS activities ($M = 3.06$, $SD = 1.55$; on a scale from 1 "entirely inappropriate" to 7 "perfectly appropriate"). The participants rated Search-Tokens as the best tool ($M = 5.78$, $SD = 1.43$), closely followed by Search-Wheels ($M = 5.50$, $SD = 1.25$). The differences with the classic form are statistically significant (classic input form versus Search-Wheels: $t(17) = -6.27$, $p < 0.01$; classic search form versus Search-Tokens: $t(17) = -6.50$, $p < 0.01$). The difference between ratings of Search-Tokens and Search-Wheels is not statistically significant ($t(17) = -1.05$, $p > 0.1$).

In answer to a question regarding the activity and engagement of their team members, the participants evaluated behavior in the classic input condition as more passive ($M = 5.39$, $SD = 0.98$; on a scale from 1 "very passive" to 7 "very active") than in both Search-Tokens ($M = 6.00$, $SD = 0.84$) and Search-Wheels ($M = 5.89$, $SD = 0.83$). The differences are, respectively, statistically significant (classic input form versus Search-Tokens: $t(17) = -2.65$, p

< 0.05) and (narrowly) not significant (classic input form versus Search-Wheels: $t(17) = -2.03$, $p < 0.1$). However, between Search-Tokens and Search-Wheels there is again no detectable statistical significant difference ($t(17) = -0.81$, $p > 0.1$).

The subjective assessment of the interface conditions from the comparative questionnaire demonstrates the differences between the physical Search-Tokens interface and the virtual Search-Wheels interface (Table 4).

Table 4 Results of the Comparative Questionnaire

	Question 1: Most appropriate for collaborative IS activities?	Question 2: Personal favorite?	Question 3: Most tiring to use?
Physical Search-Tokens	**59 %**	**47 %**	**22 %**
Virtual Search-Wheels	41 %	24 %	56 %
Classic Input Form	0 %	29 %	**22 %**

59 percent of participants found Search-Tokens to be the most appropriate tool for collaborative IS activities, followed by Search-Wheels (41 percent); no participant (0 percent) voted for the classic search form as the most appropriate (Table 4, Question 1; one participant voted for two alternative interface conditions and was thus excluded from the analysis).

As their personal favorite, the participants cited Search-Tokens (47 percent) most often. In this question, the classic search form was ranked slightly higher (29 percent) than Search-Wheels (24 percent; Table 4, Question 2).

Participants were additionally asked to select the most tiring interface condition (Table 4, Question 3); the results favor both the classic input form and Search-Tokens. Fifty-six percent of participants chose Search-Wheels as the most tiring interface condition, while only 22 percent listed the classic input form or Search-Tokens.

6.2.5 Discussion of Results

In conclusion, the opportunity of working simultaneously (RQ1) was well-accepted in the Search-Wheels and Search-Tokens interface conditions. The subjective results from the comparative questionnaire showed that Search-Tokens (the condition with the highest degree of reality) was less exhausting to use, most often listed as the personal favorite, and was evaluated as more appropriate for collaborative work than Search-Wheels (RQ2). This result is all the more remarkable considering that only half of the participants stated that they had previous experience using TUIs.

Collaboration during IS activities encompasses far more aspects than merely the simultaneous use of IS tools; for example, verbal and non-verbal communication are also vital elements. During the user study, in addition to differences in collaborative action with the interface, we were also able to observe that the activities of the triads as they worked together varied depending on the interface condition. The statements from the group interviews confirmed our observation that especially the physical Search-Tokens interface condition stimulated communication and active engagement in the triads. These behavior patterns were therefore analyzed in more detail in a follow-up user study (Chapter 6.3).

6.3 Experiment 2: Roles of Collaboration

6.3.1 Motivation

The second experiment associated with this thesis sought to clarify the impact of reality-based UIs and their characteristics on collaborative IS processes, in comparison to desktop PC-based UIs (Heilig et al. 2011). Our focus was on tightly-coupled collaboration during the exploration and filtering of search results. Such tasks are typical IS situations in which it is beneficial for people to work together (Chapter 3.2.3). In examining these tasks, the study attempted to establish in detail how interaction, communication, and strategies change based on the type of UI involved. Special attention was paid to the roles and behavior patterns that emerge during collaborative work. This study was guided by three research questions on the mechanics of co-located, collaborative IS using reality-based UIs:

- **Research Question 1 (RQ1):** How do reality-based UIs influence interaction strategies in comparison to PC-based UIs?
- **Research Question 2 (RQ2):** What impact do the two UI types (reality-based and PC-based) have on communication (verbal and non-verbal) during group work?
- **Research Question 3 (RQ3):** Are there UI-dependent differences in the roles adopted during group work?

6.3.2 Research Conditions

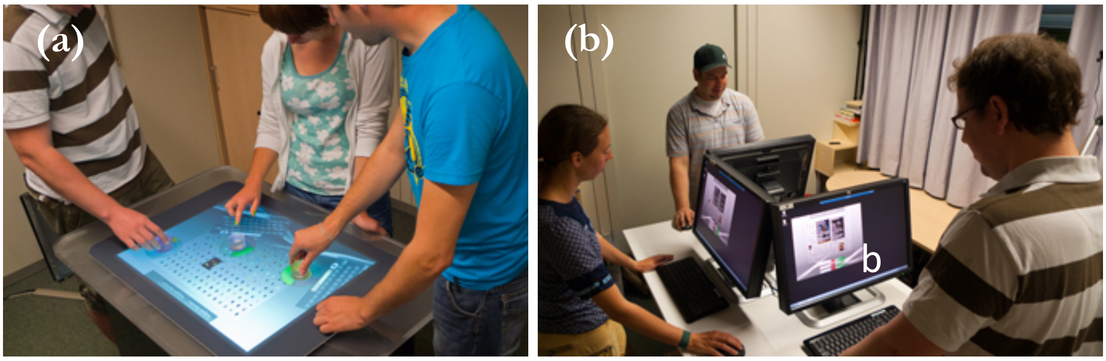


Figure 42 Experiment 2: Set-Up of the Research Conditions

(a) Search-Tokens as a reality-based UI; (b) Three Synchronized PCs as an alternative UI.

As our experimental user study was intended to explore in detail how collaboration and behavior in the context of IS would be affected by using either reality-based UIs or PC-based UIs, we developed two UI conditions (Figure 42). Each UI represents a specific interface type (reality-based versus PC-based). The experimental systems differed only in the *interaction* *mechanics* (independent variable); search, as a shared and co-located experience, remained stable to ensure a fair and valid comparison.

The result visualization and data set used in this study were the same as in the first experiment (Chapter 6.2.2). The two research conditions in the second experiment were also based upon the principles of dynamic query, weighted Boolean searches, and sensitivity, as introduced in the Search-Tokens design case (Chapter 5.3).

Reality-Based User Interface (Search-Tokens): For the first research condition, we used the Search-Tokens interface described in the previous chapter, including the highlighting functionality of the Plexiglas cylinder. In the experiment, the group had a total of three Search-Tokens to use while interacting with the system (in accordance with the group size of three participants).

Synchronized PC User Interface: We intentionally designed the second UI condition in contradiction of the principles of RBI, as a contrast to Search-Tokens. However, as we especially wanted to focus on the mechanics of RBI, certain aspects needed to remain stable. This included the co-located setting as well as the possibility for parallel interaction. Therefore, three PC-devices were triangularly arranged on a table that was similar in size to the multi-touch tabletop (Figure 42). Using a "real-time" synchronization of the visualization and filters on all clients, the participants shared one logical view of the UI (Figure 43a); using search boxes in the lower part of the screen, the participants were able to simultaneously define search criteria (Figure 43b). The sliders next to the search boxes allowed definition of the weight of the search criteria.

This setting enabled each collaborator to equally participate in interactions by using the mouse and keyboard attached to their personal PC. In this setting, the participants were able to see the faces, gestures, and posture of the other group members, to communicate with each other, and to interact simultaneously, as in the reality-based UI. The basic differences between the UIs were (1) the form factor, (2) the physically merged interaction space, and (3) the interaction modality (mouse/keyboard versus Search-Tokens and touch interactions). This allowed us to isolate the mechanics of interaction (independent variable – IV) for our experimental user study.

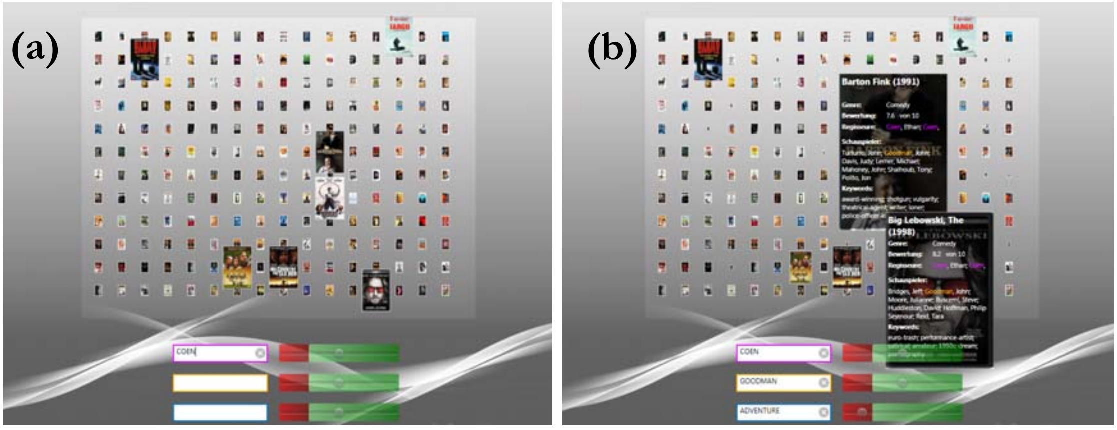


Figure 43 **Experiment 2: Synchronized PC User Interface**

(a) Participants share a synchronized logical view from different PCs and are able to simultaneously enter search criteria into the text boxes;
(b) Using the slider widgets assigned to the text boxes, participants can adjust the weight of search criteria.

6.3.3 Participants and Design

We used a between-subjects design (IV: reality-based UI versus PC) with 75 participants, who were randomly divided into 25 groups of three (triads, 12 tabletop and 13 PC groups). Participants were students or university faculty (39 females and 36 males) from a variety of non-technical departments. The average age was 26 (SD = 7.4 years). Triads are a typical setting for small groups working collaboratively on IS tasks (Chapter 3.2.2), and our participants stated that they were familiar with such situations. IS activities were also very frequent tasks for them. Furthermore, nearly all of our participants had prior experience with touch displays (e.g., smart phones).

We decided to apply a between-subjects design because we identified several aspects that might have a significant and uncontrollable influence on the results of a within-subjects design. First, the novelty of a tabletop UI with tangible components might evoke a strong "wow"-effect and lead to a bias in comparisons of the reality-based UI configuration and the PC-based UI. Second, group dynamics evolve over time as people get to know one another; this could affect the roles people adopt in a second round of tasks. Third, in within-subjects design studies, participants sometimes transfer strategies from one UI to the next. Even a counter-balanced within-subjects design might not have been able to rule out such interaction effects. We also explicitly decided to assign participants into groups of strangers. While this may not reflect a real-world situation, it allowed us a better level of control regarding inter-personal relationships and their possible effects on group dynamics.

Procedure and Tasks: After a short introduction, each group was given five minutes of instruction on their respective UI, followed by a five-minute free-exploration phase during which they could get to know the system and each other; they then worked collaboratively on a total of four tasks, two of which were training tasks. These training tasks required the participants to search for a movie object within the collection that matched various attributes (e.g., genre: "romance" or keyword: "murder"). The two subsequent "real" tasks were designed to simulate a realistic negotiation situation in which compromises had to be made. The tasks required participants to agree on a movie object within a limited amount of time. Each participant received one criterion during the first task and two criteria during the second task (e.g., keyword: "explosion", genre: "crime") that represented his or her (fictitious) interests. In order to simulate a realistic collaborative situation, the tasks were designed so that it was impossible for the group to satisfy every criterion. Thus, the participants had to negotiate whose personal criteria to minimize (e.g., by reducing the weight of one or multiple criteria) or which criteria to give up completely. A time limit of 5 minutes per task was used to control the session duration and to increase the participants' motivation to come to a decision. However, we did not interrupt users before their final decision was made, since the time limit was not intended as a definite requirement for the completion of the task. The mean duration of the tasks was 4 minutes 46 seconds (286s, SD = 74s). After completing the tasks, each participant filled out a personal questionnaire regarding their subjective assessment of the group's work and the UI. In all, the entire session took about 45 minutes per group; participants received compensation of 15 Euro.

Data Collection and Analysis: We used a variety of data-collection techniques, including questionnaires (pre- and post-test), interaction logging, and video and audio recording. Two video streams captured both the detailed interactions on the display and the overall group dynamics from a bird's-eye view perspective. In the case of the PC interface, screen capture recording and interaction logging were used to show the detailed interactions on all three displays. Each participant wore colored badges and bracelets, allowing us to easily designate their interactions in all video recordings.

Video and screen recordings were analyzed in detail. Based on several overall screenings, a complex coding scheme was developed, focusing on three aspects: (1) individual interactions of participants with the system (e.g., typing in a keyword, moving an object), (2) the visual focus and attention of participants, either to the system or among one another (e.g., turning around, looking up), and (3) the character of the verbal communication between participants.

The coding scheme was then employed to evaluate the last and most complex task, in which two criteria were given to each participant. As coding the data in this detail was impossible to accomplish in one session, we utilized multi-pass coding, with each pass focusing on one of the three aspects. To ensure inter-coder reliability, the material from four groups (two from each UI configuration) was encoded a second time by a researcher not involved in the study (statistically analyzed with Cohen's Kappa, K = 0.67). We additionally looked for interesting patterns and spotlighted such scenes during the coding sessions.

6.3.4 Results

In the PC condition, each participant in theory could work solely on his or her individual PC. However, we did not force participants to use their individual PCs. Interestingly, two groups passed up the opportunity to work simultaneously and instead shared one PC. Upon closer inspection, it became obvious that in these groups one participant took on a dominant role in solving the tasks, while the other group members showed very cautious behavior. To allow a detailed and reasonable comparison between the interface conditions, we excluded these groups, leaving us with 23 remaining triads (69 participants, 12 tabletop and 11 PC groups).

In the following, we describe how the primary interaction strategies, communication behavior, and roles the participants adopted in solving the tasks differed between the two UI conditions. T-tests were utilized to analyze the data for statistical differences.

Interaction Strategies (RQ1):

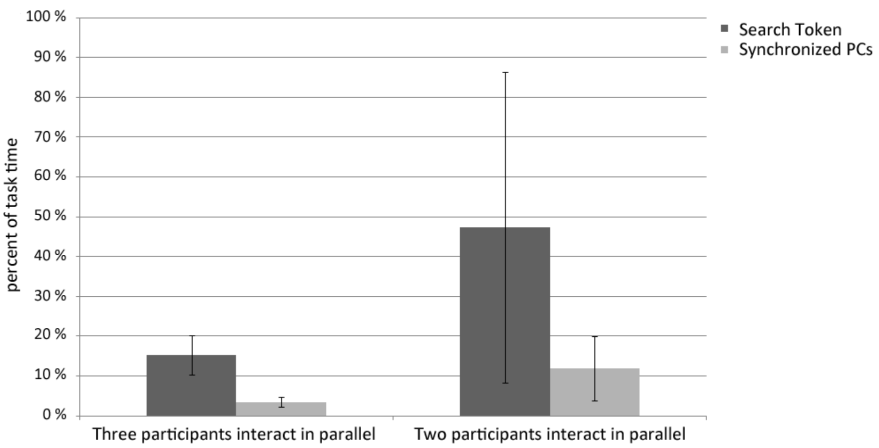


Figure 44 Experiment 2: Simultaneous Interaction

The diagram shows the time (in percent of the total duration) during which two or three participants were simultaneously working with the system.

Simultaneous Interaction – Regarding our first research question (RQ1, interaction strategies), we were interested in investigating how often people interact in parallel. This aspect is often cited as a major advantage of reality-based UIs (e.g., Hornecker 2002). To compare the two conditions, we used percentages of task time as a normalized value. The results show that the reality-based Search-Tokens condition featured more simultaneous interaction than the PC-based condition (Figure 44): overall, all three participants were interacting with Search-Tokens in parallel 15.3 percent (SD = 4.97 percent) of the time. In comparison, the PC-based condition demonstrated this behavior only 3.45 percent (SD = 1.22 percent) of the time, with the difference between the conditions statistically significant ($t(23) = 1.78$, $p = 0.04$; statistically analyzed at the group level). Parallel interaction of two participants occurred in the Search-Tokens condition 47.3 percent (SD = 39.11 percent) of the time, significantly more often ($t(23) = 2.16$, $p = 0.004$) than in the synchronized PC condition (11.9 percent, SD = 8.01 percent).

Figure 45 **Experiment 2: Token Sharing**

The figure shows two scenes in which a participant is taking over the Search-Token previously used by another group member.

Interface-Element Sharing – We identified an interesting behavior in some participants in the Search-Tokens condition. Without being asked to do so, they took over a Search-Token that had previously been used by another group member (Figure 45). Such behavior never occurred in the PC-based condition (no participant used a text box or slider that had already been used by another group member). This suggests that the threshold to intervene in the interactions of others was lower with Search-Tokens than with the PC-based UI. We observed that such behavior advanced the collaboration to a closer and more mutual level of interaction: Once the behavior occurred, the other two participants imitated it, also using the Search-Tokens of other participants on the tabletop display. However, in one case this "token-takeover" led the affected group member to withdraw and interact less often with the system.

Communication (RQ2):

Verbal Communication – The second research question (RQ2) inquired into the impact of communication. We classified group communication into process-dependent (strategic meta-contributions related to completion of the task, e.g., "Let's sort these movie objects to the right" or "I'll take the upper search box"), task-dependent (content-related contributions to solving the task, e.g., "Do you think *Gladiator* is a biography?" or "Is *American History X* a cruel movie?"), no communication, and undefined communication. However, analysis showed no significant differences between the conditions in terms of the different types of communication. For example, the triads in the Search-Tokens condition displayed 'no communication' 14.63 percent (SD = 3.97 percent) of the time. Comparing this result to the triads in the PC-based condition (16.32 percent, SD = 4.47 percent), we detected no significant difference ($t(23) = 2.08$, $p = 0.84$). A deeper analysis with process-dependent, task-dependent, and undefined communication variables also revealed no significant differences.

Non-Verbal Communication – An important aspect of non-verbal communication is the visual focus of the participants during group work as an indicator for attention. In both UIs, visual attention was largely focused on the display(s) of the system. In the Search-Tokens condition, all three participants were visually focused on the system 92.68 percent (SD = 21.34 percent) of the time, while the same was true in the synchronized PC groups 80.66 percent (SD = 24.58 percent) of the time ($t(23) = 2.08$, $p = 0.054$). Further analysis of the video material revealed that with the Search-Tokens UI, the gestures and posture of the other group members were perceived without the participants needing to look up from the display. In contrast, the participants in the PC condition made many short interruptions in order to see and perceive the non-verbal expressions of the other group members. Moreover, we noticed that several participants in the Search-Tokens condition unconsciously used non-verbal actions to communicate their involvement and active participation; for example, they expressively held a Search-Token (Figure 46) and thus demonstrated to the other group members that they were taking part in the group task.

Figure 46 Experiment 2: Token Expression

The images show three examples of participants holding Search-Tokens in their hands – using them not for interaction, but for communicating their commitment and involvement.

Roles of Collaboration (RQ3):

Profiling – The results presented above describe the differences between the UI conditions at the group level; however, we were also interested to see whether participants adopted different roles depending on the UI condition (RQ3).

For analysis of this aspect, we generated a quantitative profile for each participant based on the encoded video material. This profile was composed of the same three dimensions as had been analyzed at the group level: (1) system interactions, (2) visual attention, and (3) verbal communication. System interactions were subdivided into the following behaviors: no interaction, filter action, and object manipulation; this allowed us an understanding of what type of interaction the participant preferred. Visual attention was broken into no attention, attention to the system, and attention to other team members. Verbal communication was separated into process-dependent communication, task-dependent communication, no communication, and undefined communication. The time (in percent) a participant demonstrated one of the behaviors during the task session was plotted on the axis of a spidergram. To recognize similar profiles, we printed out the profiles of the 69 participants and asked two different experimenters to independently sort them into clusters based on visually similar behavior patterns, without knowledge of which plot belonged to which of the two interface configurations (Figure 47).

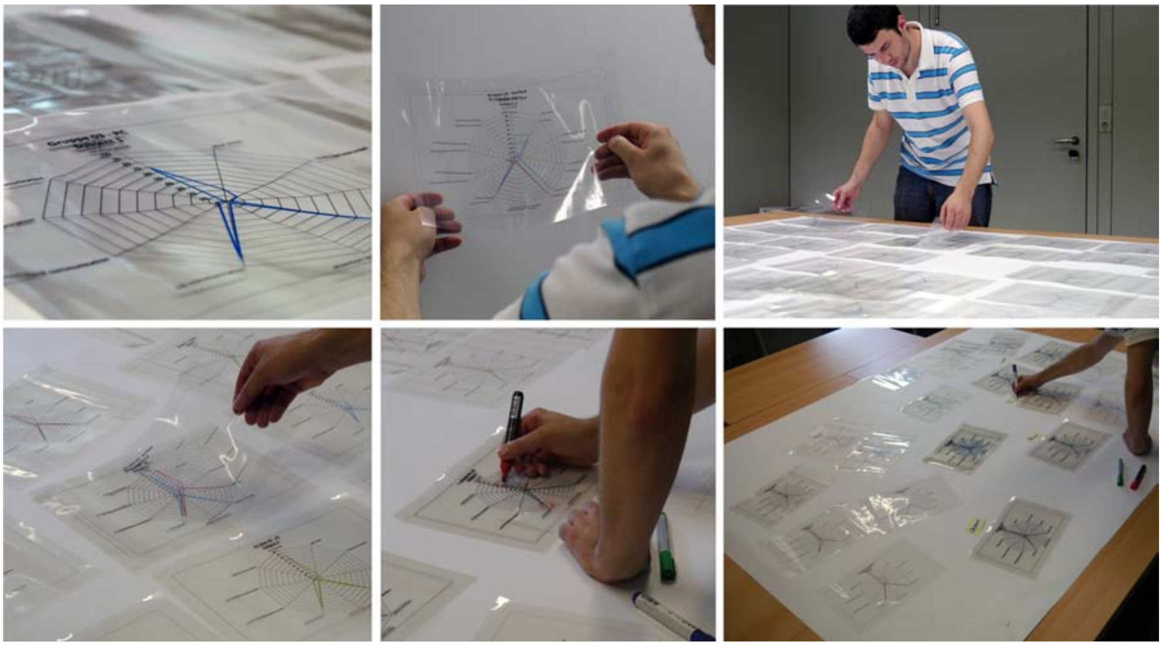


Figure 47 **Experiment 2: Extracting Roles**

To extract roles out of the data, spidergrams were used to visually identify behavior patterns.

We then took the intersections of these clusters and analyzed the behavior of the participants in the video material. Participants who displayed behavior that did not fit with the other participants in a cluster were excluded (this occurred in only two cases). We decided that a cluster had to contain a minimum of six participants in order to be regarded as a role, corresponding to a minimum probability of about 25 percent that a certain role would be observed within a given group. Following this procedure, we extracted five roles (Figure 48) that represented 39 out of our 69 participants (56.5 percent). In the following section, we present the key characteristics of each role. Interestingly, most roles can be used to easily distinguish between the two interface conditions. This thereby allows us to describe in detail how the interfaces affected role behaviors.

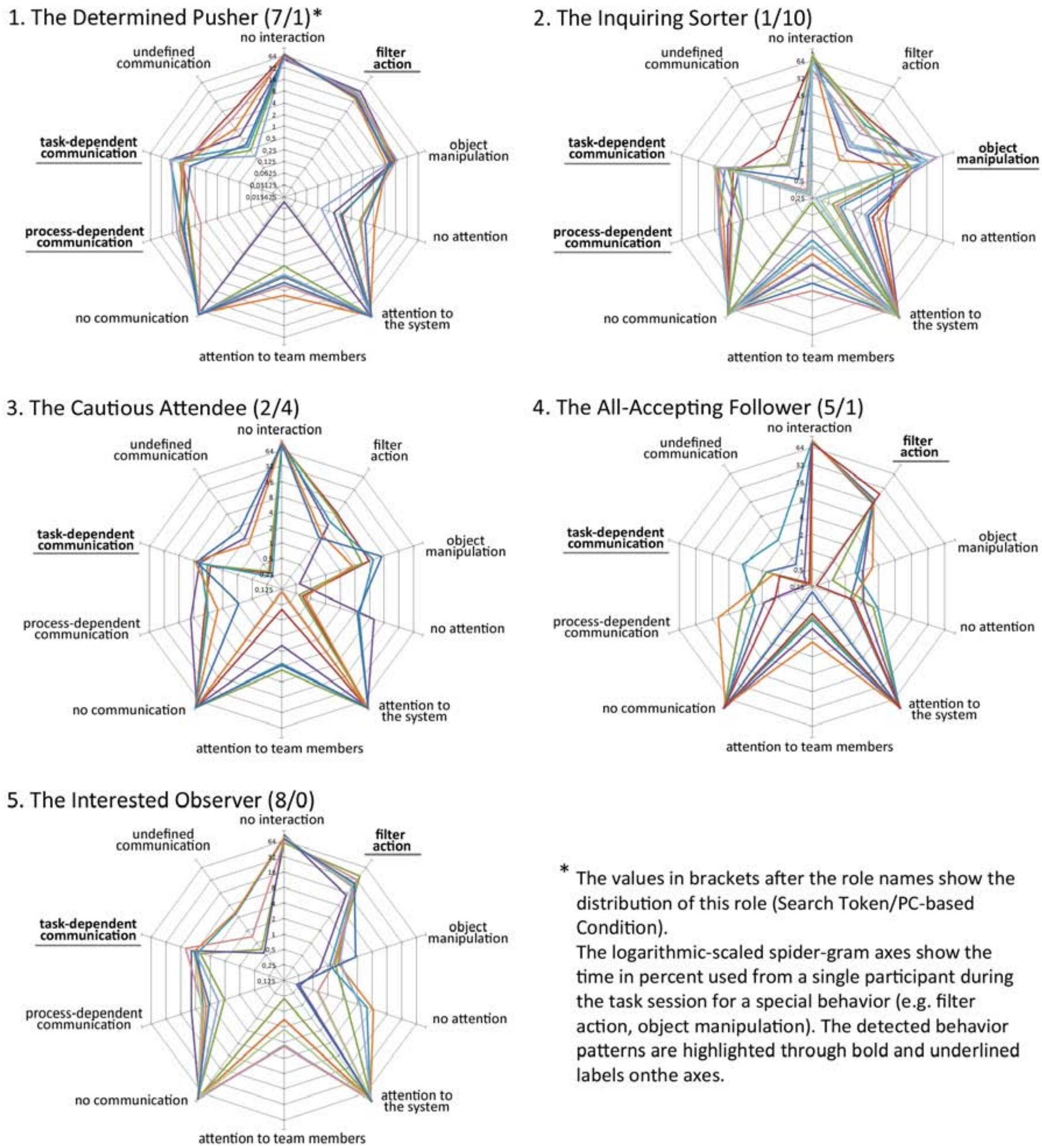


Figure 48 Experiment 2: Spidergrams of Roles

The spider grams show the profiles of the five distinct roles that participants adopted during the group tasks.

Overall, with regard to solving the tasks, we could distinguish between participants taking on a lead role and participants playing a cautious or passive role. What is interesting is that participants performed these roles differently depending on the interface configurations. We will first discuss the active/lead roles (roles 1 and 2) and then continue with the more passive/cautious roles (roles 3, 4, and 5).

Leading and Active Participants:

Role 1: The Determined Pusher – This role was adopted by at least one person in six (out of 12) groups in the Search-Tokens condition, but in only one group (out of 11) in the PC-based condition. The determined pusher is a very active participant who tries to engage the other team members to work together and solve the task. The participant is very attentive and frequently verbally contributes task-dependent comments (e.g., "Let's inspect the movie *Gladiator*"), but also makes strategic comments (process-dependent, e.g., "I propose to delete all criteria!"). Participants in this role executed many filter actions to communicate their ideas of how to solve the task. However, they also involved the other group members through discussion, gestures, and (in the case of the Search-Tokens condition) through the sharing of Search-Tokens (Interface-Element Sharing).

Role 2: The Inquiring Sorter – The counterpart to the determined pusher is the inquiring sorter. In seven groups in the PC-condition, at least one person adopted this role; only one participant played this role in the Search-Tokens condition. Like determined pushers, these participants try to animate the other team members to actively take part in group work through intensive and motivational feedback on the verbal contributions and actions of other group members. However, in contrast to the determined pushers, their interactions with the system did not focus on filter activities. Instead, the inquiring sorter interacted with the virtual media objects in the visualization (e.g., by sorting the objects found after a search) in order to highlight special correlations in the collection. As discussed above with regard to Interface-Element Sharing, these participants did not take over the search boxes of other participants.

Discussion – We conclude that the Search-Tokens condition allowed active users to take on a more dominant role within the groups. These participants took advantage of the opportunity to influence or even control group strategy, interactions (by directly controlling the physical tokens and filter keywords), and also the overall group participation (by handing over tokens or using tokens to communicate). In contrast, similar participants in the PC condition seemed to be limited in their influence on system interactions, instead focusing primarily on highlighting search results and sorting in order to take on the lead role.

We assume that one important reason for this phenomenon is that the reality-based interface is shared in its physical entirety. Thereby, conflicting activities (e.g., two people reaching for the same token) can be easily resolved by accepted and well-established social protocols (according to visibility, Klemmer et al. 2006). The shared but virtual PC condition makes resolving such conflicts much more difficult. For example, it can easily transpire that two people will try to interact with the same search box at the same time. The physical awareness of the other's actions is missing, which can lead to conflicting interactions. We presume that dominant people in the PC condition sought to avoid such conflicts and therefore had fewer possibilities to influence the group's activities. However, it should be noted that as described above dominant people in a reality-based condition can also have a potentially larger negative impact on the group.

Cautious and Passive Participants:

Role 3: The Cautious Attendee – This role emerged mainly in groups in the PC condition (in 4 groups, compared to 2 groups in the Search-Tokens condition). Participants that adopted this role can be characterized as easily conceding to the strategy decisions of other group members. While they take part in task-dependent communication, they often abandon their own ideas and most often say something in support of the decisions and interactions of other group members (e.g., "That's right", "Yes, these are the two movies"). From an interaction perspective, they only engage with the system during the initial phase in which all group members enter their keywords, but stay passive during the refinement and consolidation phases.

Role 4: The All-Accepting Follower – The counterpart to the cautious attendee is the role of the "all-accepting follower". This role, which emerged in 4 Search-Tokens groups but only once in the PC condition, is similarly characterized by an unwavering acceptance of and agreement with the strategies of other group members. While these participants seem even more cautious in verbal communication (e.g., "Yes, that's my opinion too", "This one is also a movie with a murder, right?"), they did use the Search-Tokens to interact with the system. Most of the time this occurred in parallel with another team member, following their lead.

Role 5: The Interested Observer – Although this role shares some characteristics with the cautious attendee and the all-accepting follower, we were able to identify an additional and distinct role within the Search-Tokens condition (6 groups). Most of the time, these participants simply observed the system interactions of other group members in a very interested manner (especially the sorting and arrangement of objects during the refinement phase). Their own interactions occurred mainly in the early phases via pre-decided filter actions using a Search-Token they had themselves placed on the tabletop. In later phases, while they actively participated in group work through task-dependent verbal contributions (e.g., "What movie did we have earlier?", "That is an action movie!", "No, this movie doesn't match our criteria!"), they left the execution of proposed strategies to the other group members.

Discussion – We conclude that the cautious/passive participants in the reality-based condition capitalized on a broader variety of means of expression to take part in group activities. As discussed in the results section on non-verbal communication, they were able to demonstrate their involvement in group activities through their posture, gestures, and simply by holding a token. They were also much more active in filtering the information space by use of the tokens, even in later phases. In contrast, in the PC condition, such participants were only active at the beginning of a task; later in the task, they seemed to use their PC monitor as a privacy shield that allowed them to stay passive without fear of any consequences. However, cautious participants in the reality-based condition were in greater danger of relegation to an entirely submissive role. As discussed in the results section on interaction strategies, dominant participants sometimes took over the Search-Tokens of other participants. In a few of these cases, the now "tokenless" and cautious participants withdrew completely from the collaboration.

6.3.5 Discussion of Results

With respect to our first research question (RQ1: interaction strategies), we conclude that participants working with the reality-based UI developed a wider variety of IS strategies, such as interface-element sharing and simultaneous interactions in comparison to the participants in the PC condition. We assume that this is a result of the natural and "materialized" state of interaction and its resultant qualities (e.g., visibility, physical awareness, and manipulation).

Concerning our second research question (RQ2: communication), we had mixed results. As we analyzed the groups' verbal communication, we were unable to determine significant differences between the two interface conditions. These results are similar to those of Marshall et al. (2008), who showed that verbal participation in group work is not affected by the type of input used.

However, with regard to non-verbal communication, we observed that in contrast to the PC condition, the participants in the reality-based condition seamlessly perceived the gestures of the other group members, and also that they used the physical artifacts to communicate and produce meaning. This behavior may be a consequence of the higher risk of physical interactions with the system (Klemmer et al. 2006, Chapter 2.2.2). The participants therefore communicated their commitment via extensive non-verbal feedback.

In addition to the above results, we also detected the emergence of five distinct roles (RQ3: roles of collaboration) that allowed us to easily distinguish between the two interface conditions. Participants with similar basic personalities (e.g., dominant/active or cautious/passive) often adopted somewhat different roles depending on the interface condition they were using. One determining factor for this phenomenon was the emerging social environment triggered by the reality-based UI. Another factor was the multi-faceted possibility to physically express and communicate ideas through tangible interface elements (e.g., interface-element sharing).

Implications for Design: Based on our findings, we draw some conclusions to inform the design of tools to support co-located collaborative IS activities.

The roles identified and described represent a valuable resource for designers envisioning target groups as they develop systems in a user-centered approach. For example, developers could generate "personas" based on these roles to allow a development team to get to know their potential users.

Furthermore, the identified roles highlight the fact that application of reality-based approaches in certain group configurations may cause some unpredictable effects, such as interface-element sharing. These effects may be beneficial in certain situations, but may also be counterproductive under other circumstances. We have therefore identified two crucial aspects that should be considered when designing reality-based UIs for facilitation of collaborative IS activities:

Design for Equality – Implementation of reality-based UIs (e.g., on a multi-touch tabletop) or TUIs does not automatically lead to the equitable participation of all group members. The user study showed that certain design decisions might offer more dominant people a chance to usurp control and to dictate the strategy and direction of the work (as was observed in a few Search-Tokens groups). To avoid such situations, designers should provide mechanisms that encourage participation even for rather cautious people, and also implement techniques that prevent dominant personalities from taking total control.

The Search-Tokens used in the experiment could simply be enhanced – for example, by providing more than three tokens to the users. This would avoid the typical production-blocking situation and thus guarantee that all users would always have the chance to contribute.

Design for Expressivity – Another aspect we observed in the user study, especially in participants who took on a cautious role in the reality-based condition, is the way in which such users expressed themselves. Because the higher risk of physical interactions required more commitment from group members, even cautious participants communicated their commitment. To do so, they used a variety of tools, from direct verbal contributions to physical gestures to non-verbal signs using tangible objects.

As a result of this observation, we recommend keeping group communication in the real world, as there are many social qualities that simply cannot be translated into digital systems. On the other hand, we suggest supplementing this real-world communication with additional methods of self-expression. With TUIs, users are able to communicate via tangible artifacts – for example, by handing over a token to another person to encourage interaction with the system or (as observed in the experiment) simply by explicitly holding a tangible object to communicate active participation and commitment.

6.4 Chapter Summary

In this chapter, two experimental user studies were presented that provide a rich understanding of the influences that different interface types can have in collaborative IS situations.

As a whole, these results support the hypothesis that the application of reality-based interfaces drastically alters the behavior of collaborators in small groups across multiple dimensions: interaction strategies, communication behavior, and the adoption of roles. Furthermore, the results demonstrate that although reality-based UIs can have a very positive influence (greater involvement of group members, better awareness), they may also encourage negative behavior patterns (facilitation of production blocking, e.g., by dominant participants monopolizing tokens).

The user studies concentrated on several specific activities of collaborative IS, namely collaborative filtering and exploration. More competitive tasks or tasks that demand a territorial division of labor might have quite different demands than the tightly-coupled tasks that we examined. However, the results of our study contribute an important perspective that supplements the understanding of reality-based UIs in IS activities.

Key Points

- Two experimental user studies were carried out to gain insight into how behavior changes in collaborative IS activities depending on the UI condition (traditional UIs vs. more reality-based UIs).
- The results reveal that the implementation of reality-based approaches drastically alters the interaction strategies, group dynamic and individual behavior in several dimensions.
- In addition to the many positive characteristics of reality-based UIs, the changes in behavior and work practices of groups using these interfaces may also be negative.

7 Conclusion

"You cannot acquire experience by making experiments. You cannot create experience. You must undergo it."

Albert Camus (French Novelist, Essayist and Playwright, 1957 Nobel Prize for Literature, 1913-1960)

Contents

7.1 Summary

This work investigated the potential of reality-based UIs to facilitate collaborative activities in the context of IS. As many researchers have pointed out, interacting with information does not take place in isolation; rather, it is a situated and generally social activity, there is a real need to explore new possibilities to enhance collaborative activities through the use of emerging technologies. However, many existing research approaches that have attempted to support collaborative IS activities have been developed as context-less technical showcases without regard for real user requirements.

The foundation of this work is therefore anchored in (1) people, (2) activity, and (3) context: (1) in a profound analysis and understanding of how people work together derived from cognitive science, CSCW, and social psychology; (2) in knowledge of how people interact with information during search processes, derived from IS theory; and (3) in a clear picture of the context for the execution of these activities in the implementation of our own vision of the library of the future, the Blended Library.

These three cornerstones served as the basis for the development of design cases following reality-based principles that incorporate several dimensions of collaborative IS activities.

The first design case – Facet-Browsing – is a zoom-based multi-touch tabletop application that was developed to support specific group types, namely experts and consumers as well as information intermediaries (Chapter 3.2.2). Facet-Browsing enables these asymmetric groups to browse and explore an information space collaboratively in the first stages of an IS process. Several concepts from Klemmer et al. (2006) were specifically addressed in this design case, including visibility (situated learning): Working jointly with an advanced information seeker, other group members are able to recognize and internalize new seeking and interaction strategies. In terms of thinking though doing (role of gesture, epistemic actions), exploring the information space via gestures on a multi-touch tabletop facilitates epistemic actions, which have been found to be fruitful for creative activities. Also deemed important for the design were the consciously assumed trade-offs "expressive power over reality" and "reality over efficiency" that determined the appropriate balance between reality and computational power to meet users' requirements for explorative IS activities.

The second design case, ScatterTouch, also an application running on a multi-touch tabletop system, was developed for small groups working together in a tightly-coupled fashion. In contrast to Facet-Browsing, this design case sought to support symmetric group types, such as communities of practice in the later stages of an IS process. To this end, ScatterTouch utilized a 2D scatterplot visualization projected on a multi-touch device. Augmented with distortion techniques and gestures, the design case highlighted a number of new possibilities to support analytical search activities within a reduced set of information items. In addition to the factors of "visibility" and "thinking through doing" (Klemmer et al. 2006), this design case also addressed the aspect of "performance" by enabling users to execute two-handed gestures on the screen to distort the scatter plot canvas. ScatterTouch relies on two trade-offs – "touch accuracy over reality" and "expressive power over reality" – to obtain enough computational power to support this activity.

Search-Tokens, the third design case in this research work, emphasized analytical search activities and especially collaborative filtering, which is a common activity in the later stages of IS processes. In this design case, communities of practice can analytically explore a finite set of search results via filter queries executed by multiple tangible objects acting as on-screen controls on a multi-touch tabletop display. In addition to the three previously mentioned aspects from Klemmer et al. (2006), Search-Tokens additionally incorporate the factor of "risk". Klemmer et al. (2006) observed that physical actions are characterized by risk, and that the consequence for collaborative settings is the need for greater commitment and trust within the group; we intentionally designed Search-Tokens to take this aspect into account. The design case also incorporates trade-offs – "practicability over reality" and "reality over efficiency" – to meet users' requirements at an appropriate level of reality and computational power.

These three design cases illustrate how reality-based UIs are able to support a diverse spectrum of collaborative IS activities. However, the integration of new concepts is always accompanied by changes in other dimensions, such as in group dynamics, interaction strategies, or individual behavior patterns. In order to investigate these changes, we carried out two experimental user studies with a total of 93 participants. The two studies observed people working in groups of three under different interface conditions, from reality-based UIs to interfaces based on more traditional approaches. In order to complete these studies, research methods had to be developed that would allow the evaluation of reality-based UIs. These included data-gathering methods, such as the triangulation of different video and audio streams in combination with interaction logging, and data-analysis methods, such as the development of a method to extract roles that participants adopted during the group tasks.

The following list enumerates the contributions made by this research work:

1. The Blended Library as real scenario for IS with RBIs
2. Three design cases for collaborative IS with RBIs encompassing several dimensions
3. In-depth understanding of the impact RBIs can have on collaborative IS activities and group dynamics derived from two extensive user studies

Side-Contribution. Enhancement of research methods to evaluate RBIs in collaborative environments

7.2 Discussion

Overall, we found that integrating reality-based UIs into IS activities involves changes in (1) interaction strategies, (2) communication behavior, and (3) individual behavior and adoption of roles. With regard to interaction strategies, people took advantage of opportunities to work in parallel, especially when defining filter criteria. One possible reason is the awareness of group members and their actions in the shared space. People are trained throughout their lives in direct social interaction and learned some "common" social protocols. For example, when one group member tries to grasps a token, the other group members automatically recognize this action and coordinate their own actions according to this action, e.g. no other group member grasp the token that is in the hand of another person. However, in digital systems that do not offer a shared physical interaction space, these social skills could not be applied, which may lead to a kind of "action blocking" behavior. Group members wait for the others to complete their actions before starting their own actions.

With communication behavior, although we noted no differences in verbal communication, non-verbal communication in groups using reality-based UIs was much more prevalent than in groups using more traditional interfaces. As all group members shared the same interaction space, this space also developed into a shared social space in which people peripherally perceived gestures and interactions. Participants working with traditional interfaces were limited in how they could express themselves, but reality-based interfaces allowed people to communicate on different levels (e.g., gestures in the emerging social space and on the screen, social interactions using tangibles). Offered an increased set of possibilities, participants were able to adopt these tools and discover new ways to interact and communicate appropriate to their personality traits. For example, dominant and active participants were able to integrate shy and cautious participants with "inviting" actions, such as handing over a token. Cautious persons were able to communicate their commitment and engagement by expressively holding tokens and executing gestures in the social space. However, these new tools might also offer opportunities for dominant people to take over control of a group – for example, by capturing a "foreign" token from another group member. This group member would then be blocked from contributing to the group's work and might completely withdraw from the group.

7.3 Conclusion

We are at the beginning of an era in which the digital and analog worlds will merge: The real world will be the interface; digitally-stored information will be part of reality. The essential questions for this era will be what should be controlled by this reality-based interface and which information should be digitally stored and accessed. These questions are at the root of one of the most exciting ongoing discussions in the research fields of information science and HCI. With this dissertation, I have advanced our understanding of reality-based UIs in the context of collaborative IS one step forward. Although the fascinating consequences of reality-based UIs are generally considered to be positive, there is a legitimate question regarding the dangers that could accompany this change.

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Appendix 0 – DVD

Content

- Publications
- Video demonstrations
- Material of user studies

Appendix 1 – Eidesstattliche Erklärung

Ich versichere, dass ich diese Arbeit ohne Hilfe Dritter und ohne Benutzung anderer als der angegebenen Quellen und Hilfsmittel angefertigt und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe. Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Konstanz, den 05.06.2012

Nachname: ____________________ Vorname: ____________________

Unterschrift: ____