

Applying a user-centered approach to interactive visualisation design

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1 Introduction

Humans have remarkable perceptual capabilities that tend to be underestimated in current visualisation designs [69]. Often, this is due to the fact that designers do not analyse who the users are, what tasks they want to perform using the visualisations, and what their working environments are [40].

One of the key questions, of course, is: what is successful visualisation? Usability factors, such as efficiency, satisfaction and ease of use, are used in user interface design to express the quality of interactive systems [46, 71]. Besides these generally applicable usability factors, the quality of visualisations will depend on whether they meet their goals. For instance, scientific visualisations aim to support the data exploration and decision making process [8, 73]. In this case, text books and lecture material can form a valuable source to gain more insight into goals of visualisation techniques these scientists frequently use.

Last but not least, the success of visualisations depends on the user: a good visualisation for one user may be a poor visualisation for another, because of the variance in user group characteristics and the differences in tasks to be performed [93]. Amar and Stasko [2] refer to this as the *Worldview Gap*: what is being visualised and what needs to be visualised. People give preference to the visual representations that strongly match their putative *mental model*, not so much the structure of the information [28].

Caroll [9] stated that “When we design systems and applications, we are, most essentially, designing scenarios of interaction”. This is also true for interactive visualisation design. It is a process of system design used for creating and manipulating visualisations. We define an interactive visualisation

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system as a system that not only provides different views on data (objects, structures, processes), but also enables dialogues to explore and to modify the data. Such systems should be designed for specific tasks and specific user groups. Therefore it is essential to analyse what kind of visualisation techniques should be used to support the tasks at hand and what types of interaction techniques best fit the particular user groups [92, 40, 26]. Analysing users in their context of work and finding out how and why they use different information resources is essential to provide interactive visualisation systems [91, 40]. Designers should actively involve the intended users throughout the whole visualisation design process, from the analysis to the evaluation stage [75, 34].

In this chapter, we present a user-centered design approach for interactive visualisation systems. We explain the iterative visualisation design process. Subsequently, we will discuss different techniques for the analysis of the users, their tasks and environments, the design of prototypes and evaluation methods in visualisation practice. Finally, we discuss the practical challenges in design and evaluation of collaborative visualisation environments. Our own case studies and those of others are used to illustrate and discuss differences in approaches.

2 User-centered visualisation design

Visualisation design employs an iterative, user-centered approach that globally can be split into three phases: the early envisioning phase, the global specification phase, and the detailed specification phase. In the early envisioning phase, the current situation (the users, their environments and their tasks) is analysed, resulting in user profiles and requirements. In the global specification phase and the detailed specification phase, solutions are proposed and presented to the users and other stakeholders. Each of these phases can contain more than one iteration, while each iteration consists of three activities [68] (see figure 1).

Analysis: Analysis of the users, their environments and their tasks. The first cycles, that are part of the early envisioning phase, concern the current tasks and context. Later cycles, that are part of the specification phases, concern proposed changes in the current situation and concern the systems to be built [83].

Design: The creative activity in which proposals for solutions are developed using the results from the analysis. In the first cycles the results are scenarios of the tasks and situations where the solutions will be applied. Later solutions will concern the use of future technology, resulting in low-fidelity (Lo-Fi) prototypes [65, 46]. In still later cycles, that are part of the detailed specification phase, one can include interactive high-fidelity (Hi-Fi) prototypes and finally beta-versions of the new system.

In all cycles, the product is both an explicit (and often formal) record of the proposed design decisions, and a representation intended to present to the users and other stakeholders. In the later phases, the formal records will be aimed at the engineering phase that may follow the design process.

Evaluation: Evaluation of any visualisation technique has to include an assessment of both visual representation and interaction styles. At a early stages of development, low-fidelity prototypes are assessed by scenarios [10], observations, focus groups, interviews and questionnaires. Later in the design process interactive high-fidelity prototypes are tested using heuristic evaluation, cognitive walkthrough, usability testing and other evaluation methods.

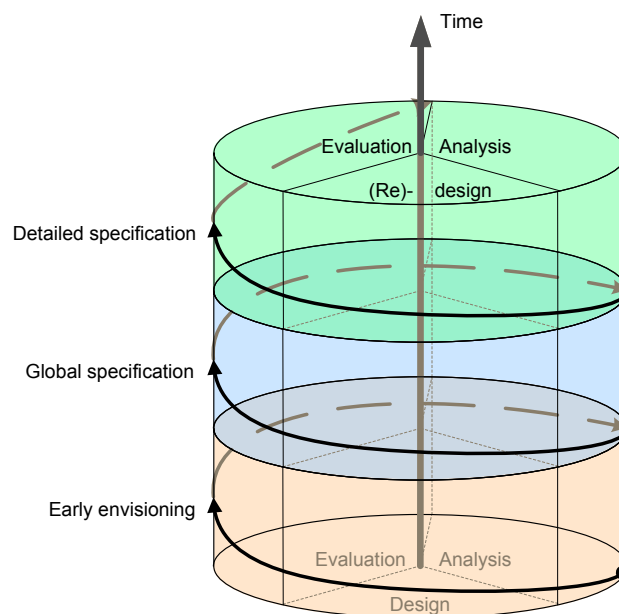


Fig. 1 User-centered visualisation design process

The design process is iterative, which means that the whole design cycle is repeated until some criterion is reached. In practice this criterion could be the targeted deadline of the client, the level of the design budget, or having reached ergonomic criteria (for example, “the targeted 90% of a sample from the intended user population was able to perform the bench mark tasks with the new system within the specified time period with less than the specified maximum number of errors”). The key point of the design cycle is that from the very beginning of the design process, stakeholders are involved to provide design ideas and feedback.

The design cycle does not guarantee successful visualisation design, however it helps to discover problems in the early stage of design. When a proposed solution is designed, usability problems will be found in the evaluation that follows design. The analysis of the next iteration will help understand why these problems exist [40].

3 Analysing the users, their tasks and their domain

Users differ in perceptual abilities and therefore have different needs in visualisation use [87]. Besides differences in perceptual abilities, other factors, such as gender, age, culture, education, cognitive and physical abilities, and economic status, are reported to play an important role [70, 55]. Additionally, different users have different tasks to perform and therefore have different needs visualisation systems have to meet [2].

Due to these differences, it is essential to perform a detailed analysis of the users, their environments and their tasks, before starting with the design of visualisation systems [21]. Several questions have to be answered [62, 6, 71, 46, 68]:

- Who will be the *users* and what are their *characteristics*?
- What are their *tasks*?
- What are the *objects* and *processes* that need to be visualised?
- What kind of *insight* should the visualisation support?

User, domain and task analysis are performed in order to gain insight into the needs and working practices of the *intended* users. Kujala and Kauppinen [39] argue to do these analyses to identify the core set of common needs and the conflicting needs. The output of the user, domain and task analysis consists of user profiles and requirements.

In our user study [43], we performed a user and domain analysis in the bioinformatics domain. We explored the working practices and experiences of scientists with bioinformatics tools and visualisations. In this domain, scientists from different disciplines, such as bioinformatics, biology, chemistry and statistics, have to collaborate to solve life science questions which cannot be solved by scientists from a single discipline. They work with huge amounts of data stored in on-line databases and use tools to access these databases and to analyse and modify the data stored in them. These scientists have different expertises in computer science, programming, and using console applications. The tools currently available are often complex and unsuitable for non-bioinformaticians [71]. Additionally, scientists from different disciplines use their own type of visualisation to gain insight into the problem and to provide “their piece of the puzzle”.

One of the problems in this domain is how to combine different types of visualisation and link the information available in the different visualisa-

tions [43]. Current bioinformatics tools do not meet the needs of the scientists. To help them perform their tasks, a new generation of tools and interactive visualisations has to be developed [38].

3.1 Selecting the user group

Different types of users often have distinct goals, perform different tasks and use different tools. It is important to distinguish these different types of user, because of their different goals in relation to the interactive visualisation system [17, 39]. For example in life science, biologists need to be able to detect differences between DNA sequences, whereas statisticians need to combine sample results in order to calculate the reliability of detected differences [43].

Ideally, the results of a user study should cover all user groups [16]. However, in practice, it is only possible to involve a limited number of users. Therefore, a careful selection of the participants is required to gain insight in characteristics of the typical (or prototypical) users and who could be relevant special types of users.

Wilson et al. [89] noticed that one of the main problems in user-centered design is to convince stakeholders of the need to involve users. And when users are involved, they are often selected by the stakeholders, for example managers. This results in an unrepresentative user selection, mostly consisting of expert users and early adopters who are willing to use the product.

In the bioinformatics domain, two groups of users can be distinguished based on their expertise with bioinformatics applications [35, 43]. The first group consists of bioinformaticians, who are expert users. Because of their education and job traditions, they are regular users of bioinformatics applications. They often have a lot of programming experience and use specialised bioinformatics tools, which are mostly console applications.

The second user group consists of biologists, who are the novice users of bioinformatics applications. They are not familiar with console applications and often have no programming experience at all. Because they need to use bioinformatics tools to perform and to interpret their experiments, they use web front-ends to access these tools. These front-ends are often direct translations of the console applications and contain a lot of parameters for configuration. Additionally, a large number of tools is available, which often confuses the biologists as to which one to use [66].

For example, ClustalW [13] is a frequently used tool in the bioinformatics domain. It is a sequence alignment tool, used for comparing DNA or protein sequences. The tool uses as input a set of DNA or protein sequences, often provided by the users by copy-paste actions of sequences found at other websites. The result is a static visualisation showing the alignments of the sequences. The tool provides a lot of parameters to optimise the alignments.

However, most biologists do not understand the algorithm behind the tool [56] and therefore often only use the default settings [43].

Another problem is that most sequence alignment tools only achieve at maximum a 50% accuracy [78]. Therefore, scientists have to manually correct these alignments using their expert knowledge, such as knowledge about structures of protein families. Interactive sequence alignment tools exist to help scientists perform these post-edits. For example, Jalview [14] is an interactive visualisation tool for editing sequence alignments. Additionally, Jalview provides different types of visualisations of the alignment, such as a phylogenetic tree (see Figure 2).

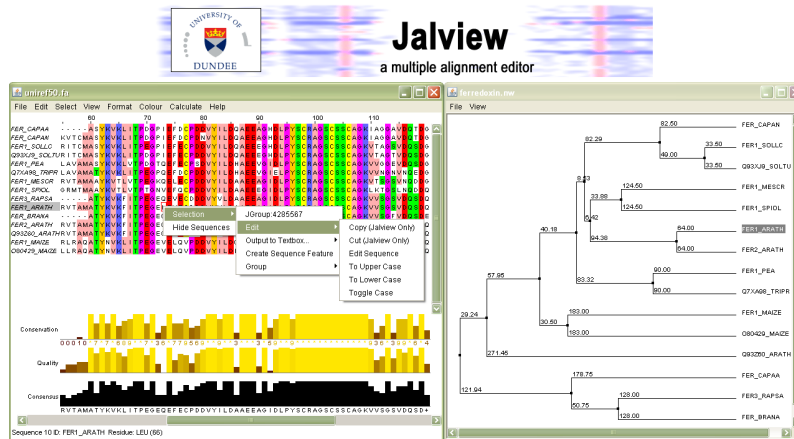


Fig. 2 Jalview, a sequence alignment editor for improving automatic sequence alignments. Right: an interactive visualisation of a sequence alignment. Left: a phylogenetic tree, based on the alignment.

If both novice and expert users have to use the same visualisation system, it is important to design help for the novice users and short-cuts for the experts. All of them could be using the same visualisation system if they are all taking the same role. A good but classic example of differentiating user interfaces for novice and expert users is the Training Wheels approach of Carroll and Carrithers [11]. In this approach, novice users only can perform an essential but *safe* set of actions to use the applications. When users become more skillful, more advanced functionality becomes available to them. Another approach to help novice users is the use of *wizards* for helping these users to achieve a particular goal [35].

3.2 Collecting data

There are two main types of user analysis techniques: quantitative and qualitative techniques [68]. In quantitative techniques, also known as studies in breadth, users' input is used to discover the different types of users and the differences in their needs. One has to be careful that measuring quantitative data does not lead to design decisions based on democracy, but on the distribution of requirements among the users. Quantitative data are often easier to compare, but a large sample is needed to measure both general and exceptional requirements.

Qualitative techniques are studies in depth, which means that more detailed information is gathered on how tasks are done. Since they require much time per participant, the number of participants is often limited.

We will describe three user study techniques frequently used in the practise of interactive visualisation, one quantitative technique (questionnaire) and two qualitative techniques (interview and observation).

3.2.1 Applying a questionnaire

Questionnaires are often used to get quantitative data from large user groups and may under certain conditions be suitable for translation into statistical information [46]. The response rate is often a problem, especially when no direct contact with the participants exists [5, 68]. A questionnaire is represented as a list of closed or open questions or a combination of both. It is important to design a questionnaire carefully, because questions can easily be misunderstood and it is not always possible to explain them during the session. To prevent such problems, it is suggested to perform a pilot study on a small group in advance [68].

Sutcliffe et al. [77] performed a user study to discover the user specific needs of the representation of information retrieval systems. They used a questionnaire in a pilot study among seventeen users, mostly researchers and students. The results of the questionnaire were used to split the group into novice users and expert users and to discover interesting aspects to focus on during the observations. The number of participants is too low to generalise results, but it can be useful as a quick method when a clear hypothesis is not known yet. However, Benyon et al. [5] argue that if the time required to construct a questionnaire is taken into account, with a small number of participants an interview will provide the same information or more with little or no extra effort. The advantage of interviews is, that the interviewer is available to explain questions and ambiguities [68].

We [43] used a questionnaire to gain insight into the experiences of novice users with bioinformatics tools. The participants were forty-seven life science students who were learning to use bioinformatics tools and resources during a course. The students did not have much expertise using these tools

and therefore were not able to give extensive feedback. A questionnaire was a suitable method for getting quantitative response. We provided space at the end for comments and motivations. However such space is not often used and if used, the comments and motivations are mostly very diverse and therefore difficult to interpret. By distributing the questionnaire during the weekly classroom lectures, we got a high response rate (90%).

3.2.2 Interviewing the users

Due to the opportunity to ask more detailed explanations, interviews form a main source of knowledge of working practices. Interviews can vary from structured to unstructured [68]. A *structured* interview is based on prepared questions in a fixed order and has much in common with a questionnaire. In an *unstructured* interview, the questions are not specified in advance, but develop spontaneously during the interview. The analysis is often difficult and the danger exists that the interviewer gets “carried away” in subsequent interviews, triggered by topics discussed in former interviews [91]. In practice, most interviews are *semi-structured*, which combines features of both structured and unstructured interviews [5, 68].

Nardi and Miller [50] used interviews to investigate how spreadsheet users with different programming skills and interests collaborate to develop spreadsheet applications. The focus of the study was to find out how these spreadsheets stimulated collaborative work and structured the problem solving process. Their study contains eleven interviews with spreadsheet users, followed by an analysis of some of their spreadsheets. They distinguished three types of spreadsheet users based on their skills in programming: the non-programmers, local developers and programmers. These three classes of users make it easier to understand the roles of different users and how these users collaborate. For example, local developers serve as consultants for non-programmers and in their turn seek programmers for assistance. The study shows that spreadsheets form a communicable means for sharing programming skills and knowledge about advanced spreadsheet features from experienced users to less experienced users.

Both novice users and expert users need to be investigated, because the first group is required for establishing a user profile, the latter for collecting information about expert procedures [46]. Interviews are time consuming, and therefore only a limited group of participants can be chosen. Therefore, we [43] have chosen to only interview expert users in the bioinformatics domain, because these expert users could give extensive feedback about their working practices and the bioinformatics resources they use. As mentioned, the novice users were analysed by distributing a questionnaire. The interviews with the expert users took place in the interviewees’ working environment to make the participants feel more comfortable, which is also known as contextual inquiry [7]. These expert users mentioned that visualisation is very

important in interdisciplinary research for discussing experiment design and results, however, it is often underused.

Closely related to interviews are focus groups: not just one person is interviewed but a group of persons [68, 49]. An advantage of focus groups is that they enable discussion among participants. One participant's opinion or knowledge will trigger additional comments and ideas from the others. However, a trained facilitator is required to lead the discussion in order to prevent some participants from dominating the process.

Kulyk et al. [42] arranged a focus group to get participants' opinions about a real-time feedback system on social dynamics in meetings. Such a system visualises different aspects of meetings, such as speaking time and visual attention of participants, in order to improve group cohesion. The focus group addressed five questions to discuss the idea of such a feedback system and showed that participants thought such a system will improve the efficiency of meetings.

3.2.3 Observing the users

Interviews and questionnaires are both useful analysis techniques for getting information on users. However, participants often fail to mention relevant aspects of their working practices and working environments, because they are either not aware of them (tacit knowledge [59]), or do not see the importance for the analyst [15, 68]. Observation is a useful technique for gathering this more implicit type of information. The observer watches the participants perform a set of normal working tasks in their natural environment to get to know the working practices of the participants.

Ethnographic observation is a frequently applied observation method that aims to observe people in their natural setting ("community of practice") without intending to influence their behaviour. The method originates from the study of (unknown) cultures. It is used in social sciences to understand group behaviour or organisational activities [68]. A classical example is the study of Latour and Woolgar [45], who observed a group of life scientists in their work environment to gain insight into both their group behaviour and their working context.

We [43] performed an ethnographic observation in the bioinformatics domain to gain insight into the way scientists from different disciplines collaborate during meetings. In such a context, it is not allowed to disturb the collaboration process for asking questions. Therefore, ethnographic observation is essential. If explanation is needed, this can still be asked after the meetings.

A drawback of ethnographic observation is that participants are aware of being observed. Consequently, there is the risk they do tasks in a prescribed or expected way instead of the way they normally do them. Participants can also get nervous by being observed, which can result in mistakes. One should

be aware that the mere presence of an observer in the community of practice does make a difference. People have to get used to this “intruder”, trust the person, and accept the presence and the habit of the ethnographer to be “nosy”.

3.2.4 Combining techniques

Most analyses are not based on a single technique, but consist of a combination of quantitative and qualitative methods [39]. Benyon et al. [5] argue for complementing interviews and questionnaires with observations. Combining different techniques in order to pursue a single goal is also known as triangulation [68]. After their pilot study by means of a questionnaire, Sutcliffe et al. [77] continued their user analysis of information retrieval systems by doing observations of novice and expert users. Both novice users and expert users were given the same set of tasks to perform. The participants were asked to think aloud and both their verbal and physical actions were recorded. The think-aloud technique is a valuable add-on to standard observation to understand what goes on in a person’s mind [68], however, people feel sometimes strange or scared doing this.

Consolvo et al. [15] refer to Labscape [3], a ubiquitous computing environment that helps biologists to do their experiments. The Labscape environment is a workflow-based environment which enables scientists to model and to visualise their procedures. During experiment execution, it structures and provides the information needed and enables the scientist to capture and structure generated data. Consolvo et al. combined interviews and contextual field research to discover the needs of the intended users of the Labscape environment. Contextual field research (CFR) has much in common with observation but in contrast to observation, interaction with users is allowed. CFR is a good technique for gathering qualitative data [15]. It is conducted in the users’ “natural” environment and the users perform their normal daily activities. Like in normal observation, a disadvantage of CFR is that users are aware of being observed.

Chen and Yu [12] compared and combined the results of existing user studies in information visualisation techniques into a meta-analysis. The advantage of such an approach is that qualitative and quantitative user studies can be combined. If existing user studies are compared, it is important to decide on the criteria for considering studies to be comparable. Examples of criteria Chen and Yu used are the topic of the study, the amount of data used and the variables measured.

3.3 Structuring the data

The analysis activity delivers complex data sets that need to be translated into user profiles, task models and descriptions of the working environments [40]. User profiles cover information about the abilities and disabilities of the users, their working environment and cultural diversity [71, 93]. Task models contain information about what tasks users currently perform and how different people are involved in performing them [85]. Task models can also be used to indicate directions to improve the current situation [2]. The description of the working environment contains information about the layout of the environment as well as information on the objects and the tools to modify these objects [83].

In our case study [43], we described profiles for three types of users in the life science domain. The first user group covers the domain experts. This group consists of the bioinformaticians who both create and use the bioinformatics tools and are familiar with console applications and programming. The second user group consists of novice users, mostly biologists. The user profiles describing the novice users show that these users often have problems using the bioinformatics tools provided by domain experts. The third group describes multidisciplinary life science teams. This profile describes that visualisation is an important means during discussion, however it is often underused in life science.

Vyas et al. [86] collected data using various methods, such as contextual interviews, diary keeping and job-shadowing, to investigate the working environment in academic research. They translated the collected data into personas, which could be used as requirements for the system to be designed. A persona is a fictitious person usually described in 1–2 pages [16]. Like user profiles, a persona is based on data collected from user studies and represents the most relevant user characteristics. However, personas represent extreme characters or characters in extreme conditions. Vyas et al. defined their personas based on demography and behaviour differences. Each persona forms a base on which to build realistic scenarios [29]. Additionally, personas form a communicable representation of what is known about the users [86].

The models of the users, their tasks and their environment together provide both constraints the future design has to meet and directions of how to improve the current situation. These models are used as input for the design and evaluation activities to reason about what valid design solutions are for the intended users.

4 Designing prototypes

Although the whole process is called “visualisation design process”, we use the label “design” to indicate the activity in which designers create things.

Designing means generating solutions based on the results of analysis activities. As Fallman [22] said:

“Design is a matter of making; it is an attitude to research that involves the researcher in creating and giving form to something not previously there.”

Design is a creative activity; brainstorming and generating alternatives play an important role [68]. The results of design are proposed solutions. These solutions are in the first place proposed or intended changes in the users’ task world, by changing, or creating new procedures, tools and/or objects. In order to analyze the intended solutions and to communicate them to the users and other stakeholders at an early stage, one needs to represent these solutions in the form of scenarios, mock-ups, simulations, interactive prototypes or beta-versions of products. The representations are used for two purposes. Firstly, they can function as proof of concept to test whether things are acceptable and whether they can be expected to meet the needs they aim to fulfill. Secondly, they act as communication media between the designer, users and other stakeholders.

Two types of prototypes can be distinguished [68]: Low Fidelity (Lo-Fi) prototypes and High Fidelity (Hi-Fi) prototypes. The first type of prototypes does not aim to look like, or behave like, the intended end-product, but is used to test early design ideas or partial solutions among the users and stakeholders. The latter type simulates the end-product and is used to demonstrate its working without the necessity of a full implementation.

4.1 Low fidelity prototypes

Low fidelity prototypes such as sketches support creativity during design [44, 72, 30]. Proposed design decisions can still be rather vague, as well as somewhat playful. Stakeholders feel free to react and to propose alternatives, and will readily elaborate and expand, since it is clear to them that details are not fixed, nothing final has been decided yet [44]. Fuchs [27], for example, used sketches to demonstrate the setup of a future office environment (Figure 3).

This approach is closely related to storyboarding. Storyboarding is a technique taken from movie making in which a series of sketches illustrate user interaction with visualisations in a cartoon like structure [5, 82]. Van der Lelie [82] mentioned that different styles of storyboarding (from sketchy to detailed) can be used to reach different goals, such as exploration, discussion or presentation. Storyboards can show different states of the interaction design, however real interaction is not possible. Sutcliffe et al. [76] used storyboarding for demonstrating their initial ideas about user interface design for information retrieval systems. The critiques about these storyboards by stakeholders helped them to gain more insight into the tacit knowledge of the users.



Fig. 3 Office of the future, a single user is collaborating with multiple participants at remote sites. Picture taken with permission from [27], © 1999 Springer Verlag.

Paper-based prototyping is a fast approach in which sheets of paper are used to suggest different system states during interaction. Stakeholders and users are willing to interpret them as early suggestions of how the intended interface should react to their behaviour. This approach was used to illustrate the initial ideas about the interaction with a user interface [65]. Each window was drawn on a separate sheet and one of the designers “plays” the computer by simulating the interactions by moving the different sheets. Rettig [65] argues that paper-based prototyping allows one to demonstrate a systems at an early stage of development and to try out far more ideas than is possible with high-fidelity prototypes.

Sketches, storyboards and paper based prototypes are all cheap approaches for creating low fidelity prototypes. Designers are not restricted to technological limitations, do not have to spend time on programming and can still identify and solve usability problems at an early stage of design [72].

4.2 High fidelity prototypes

When design ideas have matured and early solutions have been assessed and decided, representations of an intended system become less exploratory. High fidelity prototypes will look and behave like the expected end-product and can be mock-ups or even fully working products.

However, problems arise when implementation depends on technology that is not fully available yet. One way to deal with this problem is to create video prototypes to demonstrate ideas to the users in the form of acted scenarios

in which the future technology is suggested to be available [79]. Bardram et al. [4] created *virtual video prototypes* to show the use of context aware, advanced communication techniques in hospitals. They use the label “virtual” video prototyping to indicate a mixture of conventional videos with computer animation to imitate future technologies. The video prototype shows how PDA’s and interactive walls support nurses and doctors doing their daily working practises. These devices are used for video conferencing, visualising patient data and showing the activities to be performed by the particular employee.

Bardram et al. [4] claim that a video prototype will force designers to make their ideas concrete, since they have to instruct the actors what to do. The main limitation of video prototyping is that there is no possibility for real users to interact with the intended system and to experience real use. Still, a video prototype can be a good starting point for discussion with stakeholders, since they get a clear impression of the future product and may get inspired how to improve it.

A similar solution is faking future technology by using existing technology. For example, Holman et al. [31] designed Paper windows, a system that illustrated the use of digital paper. The technology of digital paper was not mature enough to demonstrate it. Holman et al. solved this by faking the technology using video projection on normal white paper. Users can interact with the prototype using pen, fingers, hand and gesture based input. The digital paper supports advanced actions, such as copying the paper’s content to another piece of paper or grabbing the laptop’s screen content.

A Wizard of Oz experiment is another way of demonstrating new ideas to the stakeholders without using actual technology. The intended users work with a system that is only a mock-up of the real system. The experimenter acts as a wizard and secretly intercepts the communication between the user and the system and executes the actions the user wants to perform [68]. Kelley [36] used this type of experiment in the early eighties to demonstrate the CAL programme, which is a calendar programme for computer-naive professionals. It uses natural language speech input (English) to interact with the system. Kelley performed a Wizard of Oz experiment to simulate and evaluate the ideas of the CAL programme input. By performing this type of experiment, he only had to partially implement the system and could ignore the limitations of natural language processing techniques.

Kulyk et al. [42] used this type of experiment to evaluate their real-time feedback system for small group meetings. As we mentioned before, the system visualises non-verbal properties of peoples’ behaviour during team meetings in order to improve the productivity of the meetings. Real implementation requires reliable computer vision and speaker recognition techniques. By performing a Wizard of Oz experiment, the use of the system could be evaluated without the need of implementing the whole system.

4.3 From prototypes to end-products

Evaluation at an early stage of development allows the solution of usability problems with less effort than after implementation [65]. On the other hand, once a design is implemented, it can and should be evaluated in the community of practice (intended context of use with the intended users) in order to check commitment to the requirements [68]. Whatever the status of the prototype, whether it is a simulation or real interactive version of the intended system, its goal is still to assess design decisions and possibly to reconsider them. Evaluation of the end-product is different as the goal is to test the implementation, which may include machine performance, platform independence, maintainability and portability. Still, even in the case of an end-product, in most cases new (and unexpected) usability problems will emerge, triggering a redesign for next releases of the product.

5 Evaluation in visualisation design practice

New generations of interactive visualisations not only have to meet user requirements but also have to enhance exploration of large heterogeneous data sets and provide domain-relevant insight into the data [38, 66]. This raises challenges in evaluation of visualisations. Innovative and complex designs need to be tested in order to check whether they meet user requirements. Existing evaluation methods are not fully applicable to new visualisation spaces and related advanced user interfaces [38]. Evaluation of any visualisation technique has to include an assessment of both visual representation and interaction styles [90]. House et al. [32] underline the low quality of published evaluations, in the sense that the findings are not appealing for visualisation practitioners since such results do not lead to design principles and guidelines to guide them. There are only few successful attempts to transform the results from different evaluation studies into general design guidelines or heuristics [12, 32, 80]. General guidelines would be useful for the visualisation community in general, including designers, developers and marketing specialists of interactive visualisation techniques.

5.1 Case studies of evaluations

Kobsa [37] compares three different commercial information visualisation systems. In this experiment, each of the participants performed a set of predefined tasks. Mean task completion time was measured in combination with observations to measure ease of use. He found that users achieved only 68-75 percent accuracy on simple tasks. In this study, the success of visualisation

systems was found to depend on the following factors: flexibility of visualisation properties, freedom of operating the visualisation, visualisation paradigm and visualisation-independent usability problems. Kobsa concludes that there is room for improvement in effectiveness of visualisations.

The lack of a generic framework is also a common problem in evaluation of visualisations. Very few studies are devoted to frameworks for design and evaluation of information visualisation techniques [2, 25, 38, 90]. Such models can help to perform evaluations in a structured way. For example, Figueroa et al. [25] introduce a methodology for the design and exploration of interactive virtual reality (VR) visualisations. They evaluated performance and user preference with several design alternatives during the early stage of development of a VR application. Alternative interaction techniques were presented to users in order to choose a technique they prefer most [25].

Koua and Kraak [38] developed a framework for the design and evaluation of exploratory geovisualisations for knowledge discovery. This study addresses the lack of evaluation methodologies and task specifications for user evaluations of geovisualizations. In contrast, Amar and Stasko [2] presented a knowledge task-based framework to support decision making and learning. Their study classifies limitations in current visualisation systems into two analytic gaps. First, the *worldview gap* between what is shown to a user and what actually needs to be shown to make a decision. Second, the *rationale gap* between perceiving a relationship and expressing confidence in the correctness and utility of that relationship. In order to diminish these gaps, new task forms are presented for systematic design and heuristic evaluation. For example, an interactive visualization system can bridge the rationale gap by clearly presenting what comprises the representation of a relationship, and present concrete outcomes where appropriate. A similar study by Winckler and Freitas [90] proposes a task-based model to construct abstract visual tasks and generate test scenarios for more effective and structured evaluations.

A number of studies also demonstrate the practical use of various methods for evaluation of visualisations. For example, Tory and Möller [80] report on heuristic evaluation [52] of two visualisation applications by experts in human-computer interaction. They conclude that expert reviews provide valuable feedback on visualisation tools. They recommend to include both experts and users in the evaluation process and stress the need for development of visualisation heuristics based on design guidelines.

Allendörfer et al. [1] use the cognitive walkthrough [53] method to assess the usability of CiteSpace, a knowledge domain visualisation tool to create visualisations of scientific literature. The cognitive walkthrough method is typically suitable for evaluation of systems with structured tasks for which action sequences can be scripted. In CiteSpace tasks are exploratory and open-ended. Allendörfer et al. adapted the cognitive walkthrough method to be fit for evaluation of knowledge domain visualisation systems. This study

confirms that each evaluation method has to be adjusted for the specific domain, the intended users and the evaluation purpose.

As explained earlier in section 3, focus groups can be used during the analysis phase to generate ideas for the visualisation designs. Focus groups, combined with interviews and questionnaires, are also common techniques in evaluation practice. Figueroa et al. [25] demonstrate the evaluation of interactive visualisations using the focus group method. The main purpose of using focus groups in this study [25] was to establish users' attitudes, feelings, beliefs, experiences, and reactions in a better way than with interviews or questionnaires. For more information on focus groups, interviews and questionnaires, see section 3.

Usability testing is the most widely used method later in the design process [61]. In usability testing, performance is measured of typical users interacting with a high-fidelity prototype or an actual implementation of a system. Usability testing is typically done in artificial, controlled settings with tasks defined by the evaluator. Users are observed and their interactions with the system are recorded and logged. These data can be used to calculate performance times and to identify errors. In addition to these performance measures, user opinions are elicited by query techniques (interviews, questionnaires) [61]. In addition to traditional performance measurements, several studies illustrate that visual and spacial perception, for example the users' ability to see important patterns, should be also included in the evaluation measures of the interactive visualisations [32]. North and Shneiderman [54] evaluate users' capability to coordinate and operate multiple visualisations in spatial information representations. The study of Westerman and Cribbin [88] reports evaluation of the effect of spatial and associative memory abilities of users in virtual information spaces. Other important evaluation aspects are, among others, influence of shared visualisations on multidisciplinary collaboration, cognitive abilities and cognitive load, peripheral attention, awareness, and engagement.

5.2 Controlled laboratory tests versus field studies

In addition to the controlled usability tests that are usually performed in the laboratory, it is necessary to evaluate an interactive system in the real context of use [20]. Unfortunately, there are very few studies in which the evaluation of visualisations is done in the real context of use. One example is a field study of Trafton et al. [81] on how complex visualisations are comprehended and used by experts in the weather forecasting domain.

Another example is a longitudinal field study performed by Seo and Shneiderman [67], including participatory observations and interviews. This study focused on evaluation of an interactive knowledge discovery tool for multiple multi-dimensional genomics data. This contextual evaluation aimed to un-

derstand the exploratory strategies of molecular biologists. While exploring the interactive visualisation, biologists were excited to discover genes with certain functions without, however, knowing how the correlations between a gene and its function are established.

In another study [28], it was found that traditional evaluation methods are not suited for multi-dimensional interactive visualisations. Therefore, the authors focused on initial testing by observing users trying out the prototypes using representative tasks. A combination of techniques was used in this study for data capturing, namely logging software, video recordings, note taking, and verbal protocol, which helped to disambiguate detailed interactions.

The field studies described here aimed to understand the actual use of visualisation tools by real users in the real use context. Though constraints like time and budget often tend to limit evaluation to the controlled laboratory settings, field studies are needed to find out what people do in their daily environment.

5.3 Evaluation setup

Several practical issues, such as stage in the design, particular questions to be answered and availability of user groups, affect the selection of suitable evaluation techniques. When setting up the user test, it is important to define the goals and the main questions to be addressed. Depending on what type of design ideas or decisions are to be tested, there may be a need to develop or adjust a visualisation prototype created in the design phase (see section 4) to engage users in evaluation scenarios. Planning the evaluation includes time for preparation, finding participants, choosing an optimal location, and performing a pilot test to measure how much time each part and the whole test session will take. All these aspects are important for the success of the evaluation study.

Simple tasks are often used in current evaluations of visualisations. However, new exploratory visualisations require more realistic, motivating, and engaging tasks [57]. Such tasks can be derived from the task analysis performed in the early envisioning phase (see section 3). Another possibility is to study related literature for relevant tasks or adopt a task from the Information Visualisation Benchmark Repository [23], based on the collection of the results from the InfoVis context [24]. This repository contains low-level tasks for evaluation of the interactive systems for visualising multiple datasets. Amar and Stasko [2] propose a taxonomy of higher-level analytic tasks that can provide support for designers and evaluators of interactive visualisation systems. In addition, it is important to let users explore the visualisation interface freely (if possible using their own data) and ask them to explain what they are able to understand [57].

Some evaluation experts suggest to invite an outside evaluation facilitator in order to avoid being biased [49]. A related solution is to split roles (e.g. evaluator, technical support person, observer, video/audio monitoring person, etc.) and use a separate evaluation protocol for each role. This helps to organise the evaluation and effectively distribute tasks [19].

It is important to ensure privacy of participants during and after the experiment [19]. It is sensible to use a special consent form which, among other things, asks permission for audio/video recordings [48]. For further information on the practical steps in conducting an evaluation study see [19].

6 Challenges in design of collaborative visualisation environments

Most published evaluation studies focus on “single user - single visualisation system” interaction. Another challenge for the visualisation designer is collaborative exploration of information. This requires new and advanced visualisation environments. Special evaluation methods are needed in order to adequately address the aspects of collaborative work in such environments [63]. Refined methodologies and reliable measures are required to assess aspects such as, for example, knowledge discovery and decision making quality. A framework should be constructed in order to adopt evaluation practices from fields like computer supported cooperative work and ubiquitous services [33, 51, 60].

New systems for collaborative use of visualisation are emerging. I-Space [74] is an example of a visualisation environment for multidisciplinary exploration of the human genome. MacEachren et al. [47] present a collaborative geovisualisation environment for knowledge construction and decision support. The e-BioLab is a collaborative environment that aims to facilitate multidisciplinary teams during project meetings on molecular biology experiments [41, 64]. The large high-resolution display in this environment allows scientists to gain new insights into the results of their experiments and to explore genomics data (see Figure 4). We are currently conducting a series of field studies in this laboratory to develop novel concepts to support group awareness [41, 84].

One more demonstration of multiple visualisations design is the persuasive multi-displays environment designed by Mitsubishi Research Lab [18]. Such environments may include *peripheral awareness displays* - systems in the environment that stay in the periphery of user’s attention [58]. Ubiquitous computing services allow feedback to the users in the periphery of their attention. The awareness supporting signs can be generated from multi-modal cues sensed by the perceptive services embedded in the environment [33]. The evaluation of awareness displays focuses on effectiveness and unobtru-



Fig. 4 Scientists interacting with multiple visualisations using large displays in e-BioLab, MAD/IBU, University of Amsterdam

siveness and the ability of visual representation to communicate information at a glance without overloading the user [33, 58].

We sketch a user-centered approach for designing visualisation environments to enhance multidisciplinary group collaboration in life sciences [84]. We are currently performing case studies to find out how to support collaboration in daily work practice between biologists, bioinformaticians, and biomedical researchers. Scenarios are used for empirical studies in micro-array experiments [64].

7 Conclusion

Visualisation systems are often designed for specific user groups which have a specific goals and work in specific environments. Analysing users in their context of work and finding out how and why they use different information resources is essential to provide interactive visualisation systems that match their goals and needs. Designers should actively involve the intended users throughout the whole process. This chapter presents a user-centered approach for design of interactive visualisation systems. Based on our own case studies and other visualisation practices, we have described three phases of the iterative visualisation design process: the analysis, design, and evaluation phase. The whole design process is iterative and actual users need to be involved throughout the whole process. They give input about requirements and provide information that helps to assess whether designs match their needs. We have discussed different techniques and methods for the analysis of users, their tasks and environment, the design of visualisation prototypes and evaluation.

An overview of evaluation studies has illustrated that there is a need for design guidelines for interactive visualisations. These guidelines should differentiate between multiple types of users performing different tasks in different

contexts to achieve different goals. Both controlled laboratory studies and field studies are needed to provide the necessary knowledge of how users interact with visualisations and of how visualisation tools affect their working practices.

Moreover, we have demonstrated that collaborative and multi-display environments demand new frameworks for design and evaluation of interactive visualisations for collaborative use. Eventually, as we understand more of our target users, visualisations will become more efficient and effective, and hopefully also more pleasurable and fun to interact with.

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