

Lessons learned from the design and evaluation of visual information-seeking systems

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Abstract Designing information-seeking systems has become an increasingly complex task as today's information spaces are rapidly growing in quantity, heterogeneity, and dimensionality. The challenge is to provide user interfaces that have a satisfying usability and user experience even for novice users. Although information visualization and interaction design offer solutions, many information-seeking systems such as online catalogs for libraries or web search engines continue to use outdated user-interface concepts developed decades ago. In this paper, we will present four principles that we identified as crucial for the successful design of a modern visual information-seeking system. These are (1) to support various ways of formulating an information need, (2) to integrate analytical and browsing-oriented ways of exploration, (3) to provide views on different dimensions of the information space, and (4) to make search a pleasurable experience. These design principles are based on our experience over a long period in the user-centered design and

evaluation of visual information-seeking systems. Accordingly, we will showcase individual designs from our own work of the past 10 years to illustrate each principle and hence narrow the gap between the scientific discussion and the designing practitioner that has often hindered research ideas from becoming reality. However, most of the times search is only one part of a higher level user activity (e.g. writing a paper). Thus future research should focus on the challenges when regarding search in such a broader context. We will use the final two chapters to point out some of these challenges and outline our vision of an integrated and consistent digital work environment named Zoomable Object-oriented Information Landscape.

Keywords Human-computer interaction · Information visualization · Visual information-seeking · Interaction design · Search · Design principles · Semantic zooming · Digital libraries

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1 Introduction

The challenge of information seeking is as old as civilization itself. Even the very first document archives dating back to 2600-2400 BC (e.g. the so-called room L. 2769 in the ancient Syrian Ebla) already organized tablets in chronological order or by genre. This, together with an arrangement similar to file cards, allowed a quick scanning of the documents [51]. The flexibility of access was increased substantially with the introduction of indices, keywords, and metadata. These enabled librarians to directly access documents without being limited by the existing order in physical space. In 1876, Cutter defined in his "rules for a dictionary catalog" that a catalog should allow one to see what the library owns and to search a document by different metadata (e.g. author, title, subject),

and should assist the selection of a book or document by adding bibliography and literary records [11]. With the introduction of online public access catalogs (OPAC) in the 1980s, the burden of information seeking was passed on from the trained search mediators or librarians to the end-users, who started to directly interact with catalog systems. Finally, the arrival of the World Wide Web introduced whole new concepts of “digital libraries”, which—following the definition by Borgman [7]—no longer limit themselves to the safe ground of well-kept single information spaces. With the World Wide Web, information seeking has quickly expanded into the “wild” and now spans public and personal information, local and remote devices, professional and user-generated data, and a vast amount of miscellaneous content. Today’s information-seeking systems are therefore turning the traditional information spaces of the past into a “personal information cloud” with an as-yet-unknown quantity, dimensionality and heterogeneity, constantly expanded, organized, and arranged by the user [28]. In such a context, search is only one essential task within the workflow.

However, when looking at today’s common information-seeking user interfaces (e.g. online catalogs, desktop or web search engines), it seems that little has been done to cope with this situation from a user’s perspective. Usability flaws that were already identified and reported in 1986 by Borgman [5] remain omnipresent in today’s search interfaces. This, however, does not mean that research has ignored this problem domain. Visualizations of search results coupled with dynamic queries have already been introduced by Ahlberg et al. [1] in 1994. Several other graphical representations of search results have been presented since (e.g. [42,52]). Some of these approaches even break with classical interface metaphors like the WIMP paradigm by integrating zoomable user interface (ZUI) concepts. By zooming into an information space, users are able to browse through it; semantic zooming provides the necessary information depending on the current scale (see the works of Bier and Good, e.g., [4, 18]). Schaefer [47] try to ease the query formulation by automatically suggesting corrections or providing a tactical term addition or subtraction combined with visual feedback. Nevertheless, only few of those concepts have found their way into real products. Based on our experience from more than 10 years of designing and evaluating information-seeking systems, visual interfaces are essential to address usability and user experience issues and to provide effective and efficient systems for even novice and non-expert users. Visual interfaces not only help during formulation of a query but also enable users to browse results and to unveil unknown correlations and tacit knowledge.

In this paper, we share our experiences and lessons learned. We will present four principles, which we have identified as crucial for the successful design of visual information-seeking systems. We will furthermore illustrate these design

principles with showcase designs and evaluation studies from our projects and hence narrow the gap between scientific discussion and the designing practitioner. It is important to note that our design solutions are from different projects dating back as far as 1999. They therefore vary to some extent in terms of their stage of maturation as well as the quality of their visual appearance. To maintain the focus of this paper, we will mention related work here but refer to the discussions contained in our related publications. To lay the foundation for our design principles we will briefly outline the relevant projects and respective application domains in the following section. In the final chapter, we will furthermore provide a perspective on upcoming visual information-seeking systems. Many researchers have investigated the information seeking process and proposed models for different domains, such as Kuhlthau [32], Shneiderman [49], Kahlbach [27], or Makri [34]. Each of them points out that information seeking is not just typing in a search and viewing a visual representation of the results but a much more complex task and often embedded in a broader activity of creative work. We will briefly discuss a selection of such models and interlink them with the proposed design principles. Furthermore, we will illustrate our vision of an integrated and consistent digital work environment, which we regard as a key requirement to fully support the user’s creative work process.

2 The source of experience—three projects and 10 years in a nutshell

The Internet System de Recherche system (INSYDER) was developed with the objective of finding, analyzing, and monitoring business information on the Web and presenting it in an intuitive way (see Fig. 1). The project started in 1999 and was funded by the European Union. The main idea was to

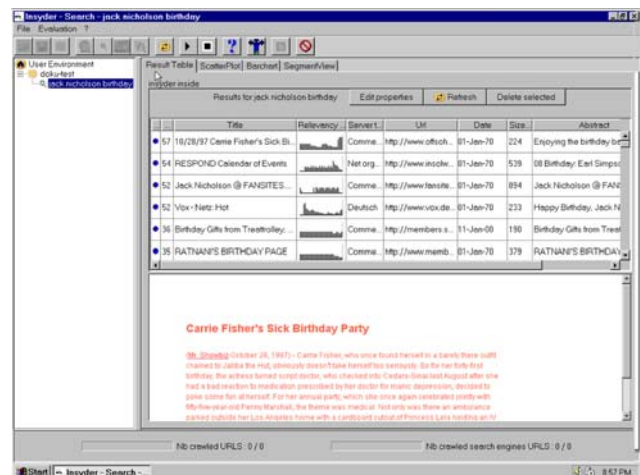


Fig. 1 INSYDER—Internet system de recherche

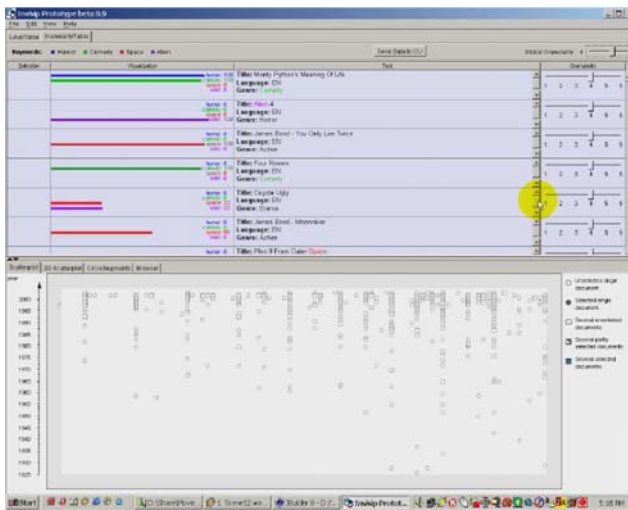


Fig. 2 VisMeB—Visual metadata browser

find and select existing visualizations for text documents that are expressive and easy to use. The challenge was the intelligent combination of these visualizations supporting different views on the retrieved documents and the documents themselves. The visualizations used in INSYDER support the interaction of the user with the system during the formulation of the query (e.g. visualization of related terms of the query terms with a graph), during the review of the search results (e.g. table and scatter plot visualizations as well as TileBars to visualize the relevance distribution of query terms) and during the refinement of the query (e.g. visualization of new query terms based on a relevance feedback).

Based on the INSYDER experiences and evaluations [35], [44] we developed VisMeB, a Visual Metadata Browser (see Fig. 2). VisMeB was part of the EU project INVISIP that tried to facilitate processes and actors of location site planning. While the basic idea of INSYDER, i.e., to use expressive and intuitive visualizations remained the same, VisMeB further enhanced these visualizations as well as the underlying interaction design. For example, the table visualization evolved into a LevelTable and GranularityTable view, allowing the user to express different degrees of interest.

In the following project MedioVis, the application domain was transferred to digital libraries (see Fig. 3). While INSYDER and VisMeB targeted expert users, our main goal for MedioVis was subsequently to simplify the usage in order to provide a high usability even for casual and novice users. Based on the findings in our VisMeB evaluation studies [15, 30, 33] we accordingly redesigned several visualization components and introduced novel interaction concepts. Since 2004, MedioVis has been accessible on more than 150 workstations in the library of the University of Konstanz. It allows users an alternative approach, alongside the standard online catalog system, to search through more than 70,000

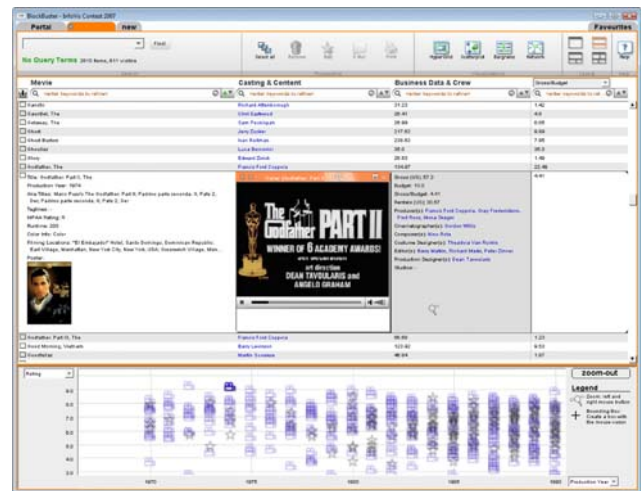


Fig. 3 MedioVis—Visual information-seeking in digital libraries

multimedia objects such as movies or documentaries. A particular challenge was the seamless integration of services, both catalog and web services such as library accounting or GoogleMaps. By directly interlinking these with the catalog objects, we address the Mashup and Web 2.0 concept from a whole new direction. Furthermore, we enriched the information space with additional, heterogeneous data from the web such as images or video trailers. To allow access to these objects, the interaction design was revised by comprehensively integrating zoomable user-interface concepts. This approach allowed us to support not only analytical but also browsing-oriented search strategies. In addition, we particularly addressed the esthetic design to enhance the user experience.

3 Design principles and solutions

In the following section, we will present four principles based on our experience in the design and evaluation of visual information-seeking systems. Briefly summarized, these are

- *Support various ways of formulating an information need.* Humans have different needs when searching for information. This results in sometimes very concrete information needs and sometimes only vague ideas of what to search for. Therefore, it is essential that the system provide different ways of formulating such an information need, depending on the kind of information the user already has. We will present visual query preview, query expansion and query refinement techniques to address this issue.
- *Integrate analytical and browsing oriented ways of exploration.* When searching for information, users might come across interesting objects they were not actually

looking for. Some users might want to ignore them to reach their initial goal as quickly as possible without being distracted. Others, however, might end up being triggered to explore some of the newly discovered information right away. In reality, users often switch between these different modes, requiring design solutions that inherit a seamless integration of analytical as well as browsing-oriented ways of exploration. To illustrate such an interaction, we will present two different approaches, one based on a table and a second based on a scatter-plot.

- *Provide views to different dimensions of an information space.* Today's information spaces are often multi-dimensional. Offering just a single dimension when searching is often not enough. Imagine someone searching in a movie database. Although the primary interest might be to find one or more specific movies, there are several other interesting dimensions. For example they might be interested in the social relationships between movies, which actors worked with which directors or producers, etc. Other dimensions might be of temporal or geo-spatial nature. We will present several visualization techniques that address this issue and will outline how these can be integrated and combined in one system to allow users to switch between different dimensions without losing the context.
- *Make search a pleasurable experience.* People in industry and research are more and more aware of the fact that the success of a product depends not only on the functionality and usability but also on several other factors, sometimes considered as more "soft factors", such as an aesthetically appealing visual design, joy of use, or other hedonic qualities such as identification or stimulation [21]. These factors are often subsumed under the term user experience (UX). We will illustrate by a redesign of a visualization technique in collaboration with communication designers how such factors can influence functionality and usability as well, and are therefore indispensable for a successful visual information-seeking system.

3.1 Support various ways of formulating an information need

Formulating an information need is one of the most important aspects for visual information-seeking systems. Unless we have systems that can perfectly predict what a user is searching for, we are depending on their ability to somehow express this information need. Borgman [5] identified query formulation in early online catalogs as one of the most error-prone steps in an information-seeking process. This observation has been confirmed several times over the years (see, e.g., [6,38]) and leads us to conclude that the situation has not changed much. From a user's perspective we can identify two

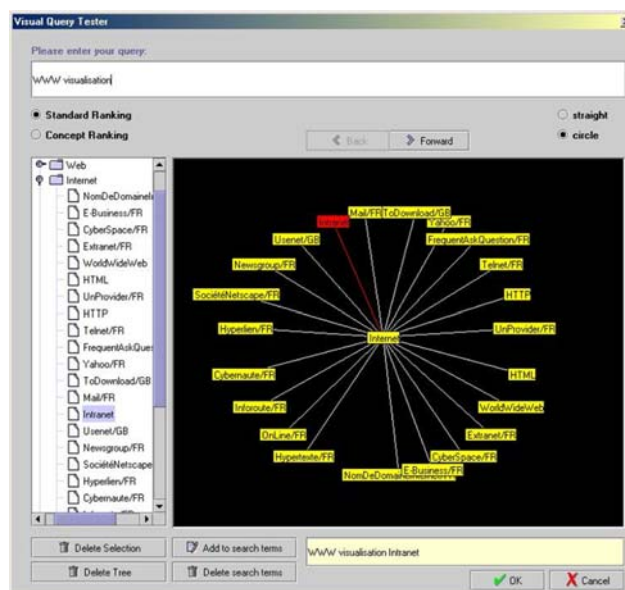


Fig. 4 Visual query expansion (INSYDER, see [44])

main challenges: (1) To support users when they have rather precise information need but have difficulties in expressing this need with keywords (known-item search). (2) To support users when they do not know what exactly they are looking for (open-ended tasks). Therefore, we also regard query-refinement techniques and filters as relevant techniques in this context. Several information visualizations have proven helpful in addressing the first issue. For example, InfoCrystal [50] and VQuery [26] are based on Venn diagrams and allow the user to see which keywords match well with each other in terms of the result set. In the INSYDER project we followed a different approach by designing a visual query expansion, inspired by previous work (e.g. [13,20,39]). The basis for such a technique is an underlying knowledge base or thesaurus. Although this is difficult to create in heterogeneous information spaces, our experiences with INSYDER demonstrated that, even in the context of the Web, it is feasible via a semantic net approach [44].

We visualized the query expansion in a graph layout (see Fig. 4). Keywords entered are represented in the center nodes and corresponding keywords from the thesaurus are shown as leaves. Expanding or hiding a selected branch supports overview and details. Users benefit from using the visual query in two ways. First, they can browse the underlying knowledge base to find more accurate keywords, requiring the cognitively less demanding recognition instead of recall and also avoiding misspellings. Secondly, they can expand their original keyword query with additional terms from the knowledge base, which will result in a more precise result set. Thereby, this technique supports the user interactively throughout the query formulation process. The second issue might be for example addressed by self-organizing maps

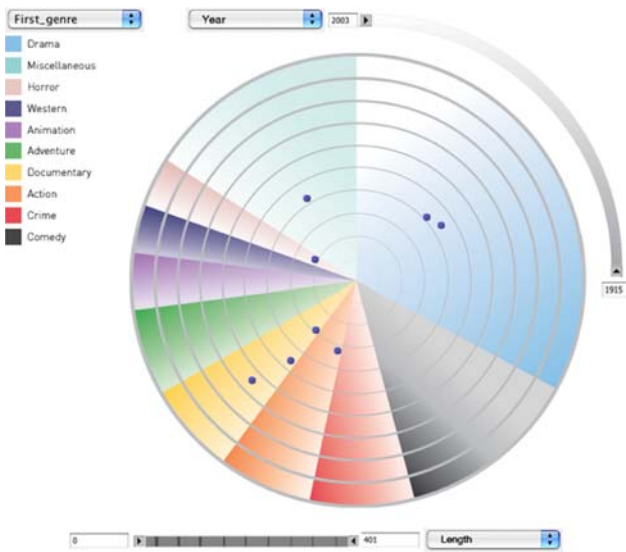


Fig. 5 Circle segment view (VisMeB, see [33])

(SOMs) [31]. These organize the information space, for example based on keywords provided by the user and then visualize a semantic clustering of the data. However, SOMs are hardly interactive since the maps take some time to calculate. We used a different approach by designing a Circle Segment View (CSV) visualization [30] to provide a more interactive solution. The CSV is a metadata-driven approach to visualizing an information need (see Fig. 5).

A circle as the basic element is divided into several segments. Each segment represents one category of a certain categorical metadata. For example, the different characteristics of media type could be mapped on the circle segments such as DVD, VHS, stream, etc., or different library sections as in Fig. 5. The number of documents matching a type determines the size of each segment. Different colors are used to make it easier to distinguish between the segments. Furthermore, each object is represented on the circle via a blue data point. The position of the data point within one segment allows the mapping of two additional items of numeric metadata. In our example, this could be date and popularity. One of them is mapped on the angle and the other on the radius. Two double-sliders allow a dynamic adjustment of the numeric metadata, e.g., to limit the document size to a certain span. Thus, we can quickly see how the documents are distributed within each segment along the two dimensions of date and document size. Different categorical variables can be chosen via a drop-down box. By selecting one, or several segments (or even single data points), the user can select these as their visual query for further analysis. We compared an earlier version of the CSV with a textual form-filling interface in an experiment with 20 participants. Results showed that further work had to be put into the intuitiveness of the visualization; nevertheless, 19 out of the 20 participants could have

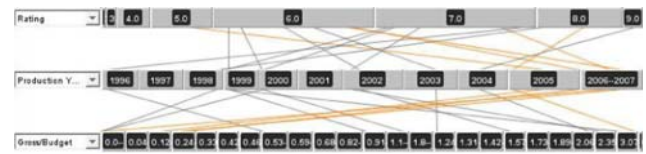


Fig. 6 Parallel bargrams (MedioVis, see [45])

imagined working with the CSV on a daily basis [30]. The CSV in Fig. 5 already tried to enhance the intuitiveness by placing the sliders in a way that emphasizes more clearly the mapping to the circle dimensions (see Sect. 3.4).

Another technique we use in our current project MedioVis is called Parallel-Bargrams (see Fig. 6), based on the work of [53]. A single bargram is split in accordance with the distribution of a selected metadata. The size of each segment again corresponds to the number of data points. Several bargrams of different attributes can be displayed simultaneously. Furthermore, connecting lines between these bargrams are shown interactively and serve as a parallel coordinate visualization to discover correlations and characteristic distributions of the data among attributes. As with the CSV, the user can specify a query by selecting one or more segments. Both the CSV as well as the parallel bargrams can also be used as query-refinement tools in terms of a dynamic query.

Beside these specialized visualizations, we included intuitive and easy-to-use filtering options for our main result's exploration visualizations which will be described in more detail in the next section. For example, we enhanced our scatter-plot visualization with zooming, allowing the filtering of the information space in accordance with the zoomed region [45]. In our table visualization we included a table filter, allowing the user to specify additional keywords for each column as a dynamic filter [25].

3.2 Integrate analytical and browsing oriented ways of exploration

In the literature, it is generally assumed that there are different kinds of search strategies ranging from an analytical, known-item search to a browsing or interest-guided search strategy [2,36]. While many researchers have tried to build different interfaces for different search types, we think that it is important to find solutions that integrate these different search strategies in a coherent and flexible way since users might frequently shift between strategies.

Imagine the following situation: you have searched in a movie database for movies directed by Steven Spielberg. The system now offers you a result set of movies. For an analytical exploration, it should integrate possibilities to compare these movies by several attributes, apply filters to them or visualize them differently to see correlations. On the other hand, information should also be presented in a way that might inspire

your current task, offer possibly related information and let you browse through the information space.

Regarding the basic result-presentation technique, many systems use list views (e.g. most of the web search engines), showing a certain number of results (often ten) per page, enriched with some metadata information. However in an early experiment with 40 participants presented in [44], we were able to show that users who performed specific and extended fact-finding tasks (see [48]) significantly preferred a table view compared to a list view, while performing nearly as well in terms of task times and task accuracy. In the following development phase, we improved the table view in terms of text readability and navigation features, matching the standard set by HTML list views, and discovered in two follow-up experiments that users were now able to solve tasks significantly faster when using the table view while still preferring this kind of result presentation compared to the list view [16, 19]. Table views offer a more structured view and allow an easy comparison of results, which is further facilitated by the ability to quickly re-sort the table by different attributes. However, there is a danger of becoming lost in “table space” if too many columns are needed to display all the attributes. In our early solutions, we therefore introduced the concept of the LevelTable and GranularityTable [33]. The LevelTable allows switching between several levels, each providing a different set of attributes. The idea is that, step by step, more detailed or complex attributes appear, while other attributes disappear again (see Fig. 7, the upper two screenshots). The GranularityTable allows users to change the degree of information for each document separately via a slider widget and therefore avoids abrupt switching between levels (see Fig. 7, lower screenshot). Based on further evaluation of the results of the study cited above (see [44]), both concepts also offered the possibility of integrating not only meta-data in terms of textual information but also visualizations such as bar charts or tilebars. This means that the user did not have to switch between different views (as in INSYDER) but was provided with one integrated visualization that offered different views on different levels (see Fig. 7). We evaluated these two concepts in one of the above-mentioned experiment with 32 participants [16]. In particular, searching for and comparing several documents were performed significantly faster than with a list view. However, we also discovered that some of the different levels were hardly used (e.g. Level 1 in the LevelTable).

Based on these results and inspired by related work such as the DateLens [3], we developed the HyperGrid concept [25]. Its basic idea was to merge the concepts of a table-based visualization with details on demand and browsing functionality, integrating a direct-manipulative zooming interaction. The HyperGrid groups all attributes of a document or object by three aspects of interest [46]. The grouping is done based on the semantic similarities between attributes and is modeled

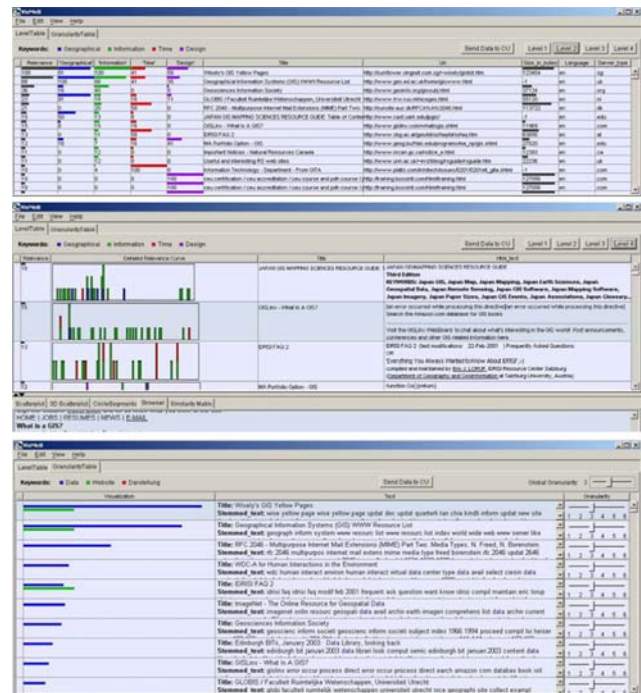


Fig. 7 From top to down: LevelTable Level 2, LevelTable Level 4, GranularityTable (VisMeB see [33])

in our attribute space concept. At first glance, the HyperGrid looks like a standard table with each aspect of interest represented in one column. Users are able to zoom into a cell, however, resulting in an enlargement (see Fig. 8). Depending on the zooming duration, which therefore directly corresponds to the users’ degree of interest, more attributes appear seamlessly. This underlying technique of a semantic zoom was first introduced by [41].

While this is a very intuitive and direct interaction, it also allows us to integrate very heterogeneous attributes such as images or video clips in one coherent visual presentation. Furthermore, we are able to merge an attribute or metadata-focused view (the table) with an object view. Users can zoom into a cell until they reach the object itself, which is presented in an overlay window. This window only covers the cell and thus the context is still preserved. External information spaces can also be integrated, e.g., standard web sites, but also web services such as GoogleMaps. To allow dynamic filtering, we integrated the table-filter concept introduced in Sect. 3.1 For easier comparison, a user-adjustable additional column allows users to grab attributes that are deeply hidden in the information space. Our qualitative user tests and interviews (e.g. [25]) showed that the zooming interaction provided an intuitive way to access details on demand. Besides, users really liked to “play around” with the interface. Nevertheless, we also found some usability problems. For example, the tested version offered too many interaction possibilities within each cell, and that seemed to confuse

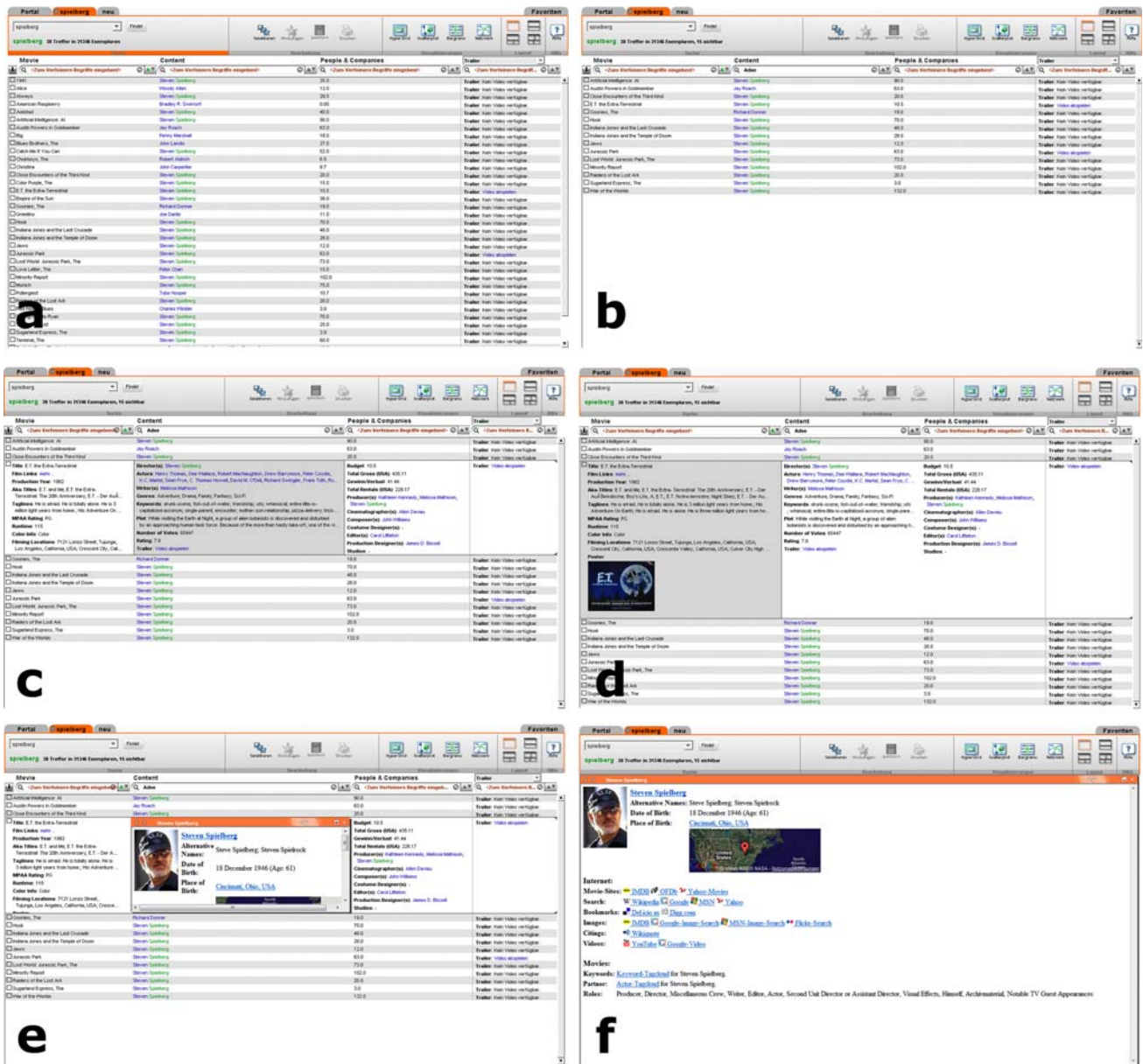


Fig. 8 HyperGrid result visualization (MedioVis see [25])

our users. Results also indicate that it is important that new attributes appear during the zooming operation in a comprehensible manner.

As an alternative visualization, we developed the HyperScatter [12, 17, 45]. The HyperScatter is a zoomable two-dimensional scatter plot that allows an overview, and the exploration of correlations between quantitative or categorical data (see Fig. 9). It further supports the effective selection, zooming, and filtering of user-defined subsections of the plot and therefore especially supports quantitative filtering and reasoning. For accessing details on demand it integrates the same interaction concept as the HyperGrid. Clicking on a data point triggers an animation and the corresponding detail

information is displayed along the different aspects of interest in an overlay window. We think that such a zoomable scatter plot is especially suitable when screen space is limited (for example, on mobile devices such as smart-phones or PDAs).

We therefore did a couple of studies where we explored different zooming and presentation techniques for scatter plots on small screens. In [8] we compared a zoomable scatter plot with an overview-enhanced version (see Fig. 10).

The overview was integrated to reduce orientation problems when zoomed-in and also offered additional interaction possibilities such as quickly “jumping” to a certain destination. Zooming into the scatter plot was realized by simply

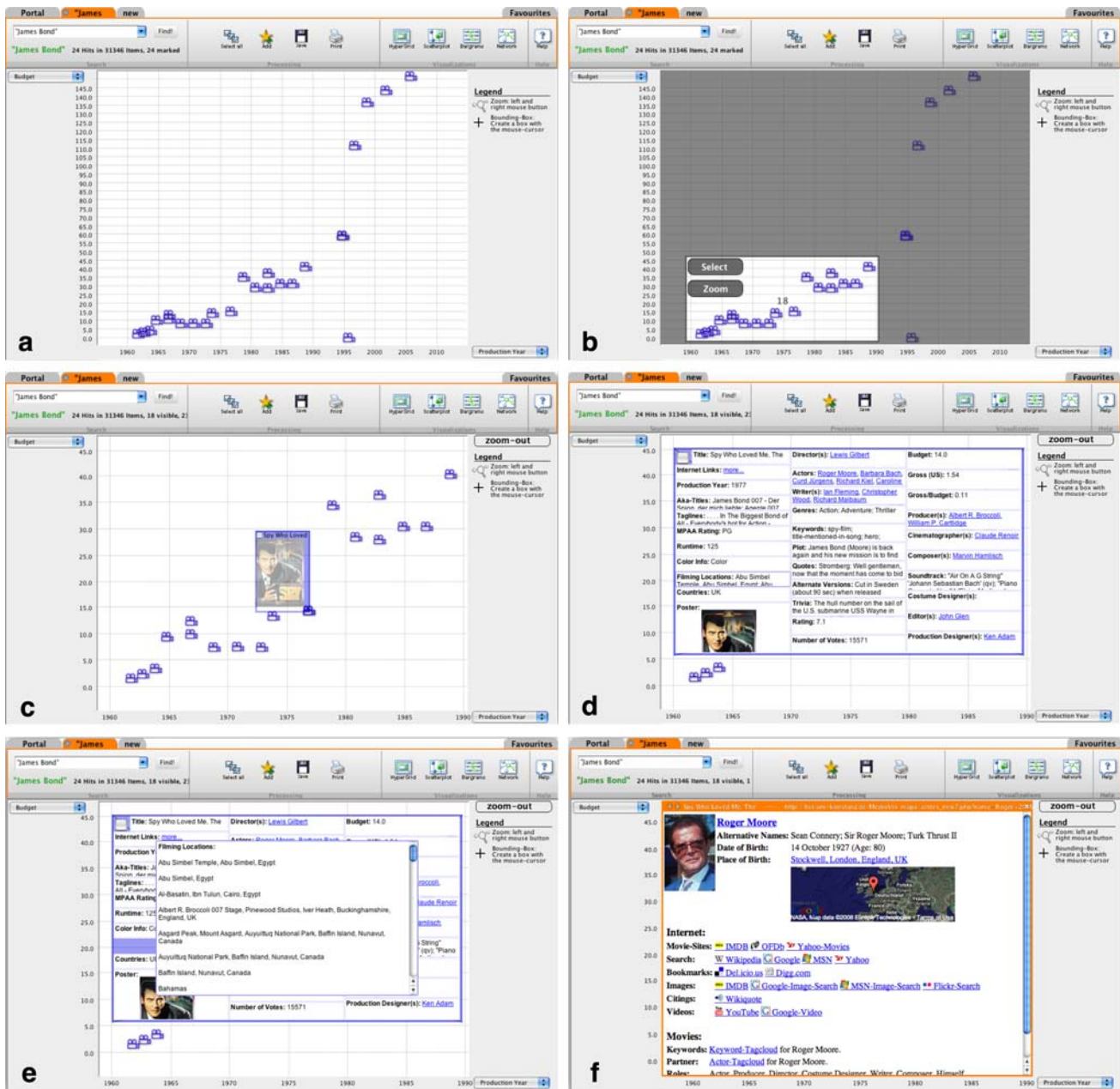


Fig. 9 HyperScatter result visualization (MedioVis, see [12])

tapping on the screen, which triggered a fluent zoom animation. Our experiment with 24 participants showed that in the case of a small screen this is a clear space trade-off. About half of the participants consequently preferred the overview-enhanced scatter plot while the other half preferred the scatter-plot-only interface. Regarding task performance, the latter outperformed the overview version significantly, probably due to the more complex interaction and the need to constantly shift the attention between the two views. For desktop-sized interfaces and very large information spaces, we, nevertheless, think an optional overview is a suitable

approach to preserving the context for the user. There are two reasons for this. First, in a desktop environment screen space is not especially limited and therefore an additional overview might not have that much of an influence on the usability of the detail view. Second, a larger information space might intensify orientation problems since users have to zoom in much more. Alternatives are focus+context techniques such as the fisheye technique [15]. In a second experiment (again with 24 participants) we compared a zoomable scatter plot application with a fisheye-enhanced scatter plot (see Fig. 11 [9]).

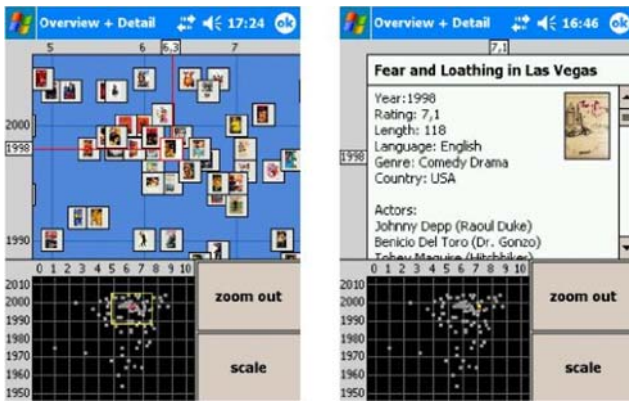


Fig. 10 Overview-enhanced scatter plot (see [8])

The latter allows for users to zoom-in by specifying a certain region, as with the HyperScatter presented above. This region is then enlarged, causing the surrounding areas to become visually distorted. Data points can be accessed by tapping in their vicinity and, accordingly, an overlay window appears in an animation showing more details. In our experiment, users clearly preferred the fisheye interface. We assume that in our case the fisheye benefited from the abstract representation of the scatter plot diagram. Since the distortion algorithm largely preserves the orthogonal order of items, it integrates very well into the scatter plot layout. Furthermore, our participants especially liked the facility to select regions of interest as an alternative to the standard zooming animation triggered by tapping and holding on the screen. The results therefore influenced the current design of the HyperScatter, integrating the “bounding box zoom” and the direct access to data points.

We recently conducted a study to compare the HyperGrid and HyperScatter concepts in terms of their usability and their ability to work in practice, and not just in the controlled

environment of a usability lab [17]. We were also interested in whether the HyperScatter concept could serve as a stand-alone visualization, or if it should be combined with other tools. Since we used a novel longitudinal study design, we want to outline it briefly. We implemented both techniques as stand-alone systems with a movie database of several thousand movies as the data basis. We chose a longitudinal study design so that our five participants were able to learn how to use the systems and then use them for their own tasks. Initially, we started with eight participants but suffered three dropouts. The study lasted a total of 2 weeks—1 week for each of the two systems. Our participants were therefore able to work with both systems, compare them, and judge them accordingly. We used a triangulation of several methods to gather our data. First, our participants were introduced to the system and asked about usage during three interview sessions at the beginning, in the middle, and at the end of the 2 weeks. Second, our participants were equipped with printed diary forms. They were asked to complete them after each system usage, noting the type of task, any problems experienced, and overall satisfaction. While the latter provided us with detailed in-situ information and user emotions, the interviews allowed the participants to give a more reflective judgment of problems, and also of the things they found useful and fun. Thirdly, we combined these two qualitative approaches with interaction logs, capturing all user interactions on our central server unit. This provided us with the possibility to cross-validate the data gathered, and find out which parts of the systems were used and which functions might be obsolete. Since motivation is always a crucial aspect in longitudinal field studies, we provided our participants with a weekly assignment. While it was possible to solve this assignment within 20–30 min, it guaranteed us some basic system usage and we also hoped that users would find the tasks interesting enough to keep using the system later on.

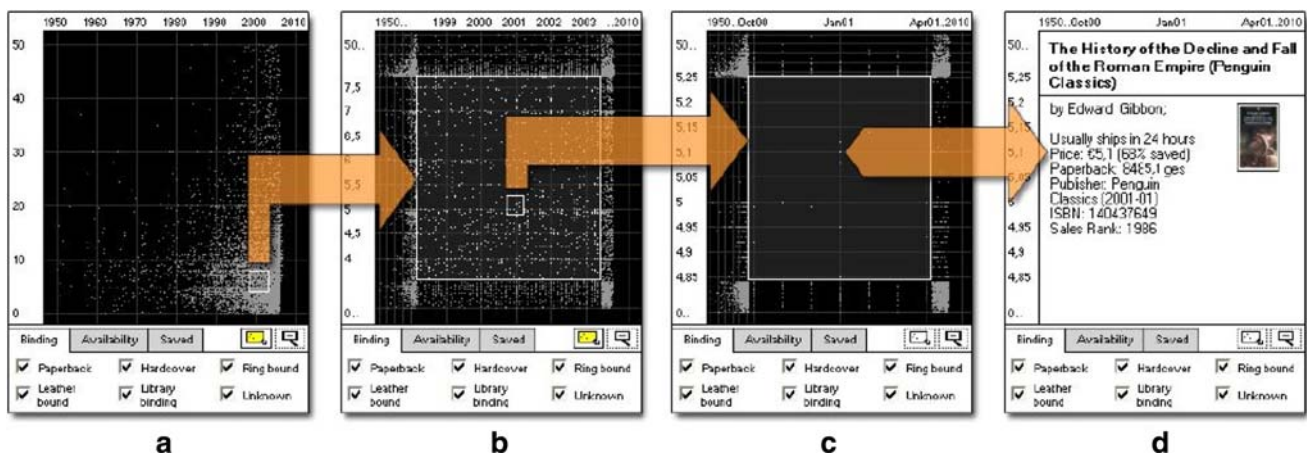


Fig. 11 Fisheye interface: a and b show a recursive distortion to remove visual clutter; c the user taps an item to access its details; d shows a record card representation. (See [9])

Our results showed that both visualization techniques worked reasonable well and two participants even asked if they could continue to use them despite some technical bugs that limited the usability. Switching to the second system after 1 week was perceived as quite an easy task, mainly due to the similar interaction concept applied in both systems when accessing an information object. We also found that the HyperGrid was better suited to searching for one specific object, while the HyperScatter provided ways to compare information objects and look for interesting clusters and correlations. In both cases, users took advantage of the browsing possibilities and especially liked the integration of external web services such as www.youtube.com and www.imdb.com. They could therefore focus on one single system and did not have to constantly switch between webpages with different interfaces. Interestingly, two of our participants came to the conclusion that it would be beneficial to combine the two approaches in one system and the other three were also positive about this possibility when asked. The question of how to combine these visualizations will be further discussed in the following design principle.

Regarding the methodology, we were pleased by the outcomes of our study. Diaries and interviews did indeed result in the identification of overlapping, but also different, issues. The combination therefore made sense. Furthermore, the interaction logs allowed us to judge the qualitative results. For example, we were able to validate the usage times given on the diaries and also identify if someone had only used the system for a short time before an interview session, and we could therefore judge the issues mentioned by this user accordingly.

3.3 Provide views to different dimensions of an information space

Today's information spaces are in many cases multi dimensional. This means that they can be examined under a social dimension or a geographical dimension, for example. The system therefore needs to provide specialized views to provide access to each of these dimensions and the respective relationships in the data. Furthermore, in many cases it might be important to view several dimensions at once or to "pipe" data through several dimensions sequentially. The latter, for example, allows a sequential filtering while the former allows the user to quickly obtain an overview of the information space along different dimensions in order to identify the interesting aspects.

Imagine the following example: we are accessing an information space about movies with visualizations such as the HyperScatter or the HyperGrid. These allow us to get more information about the content of the movies or even the actors in the movies. However, it is difficult to discover hidden relationships such as which actors worked together on

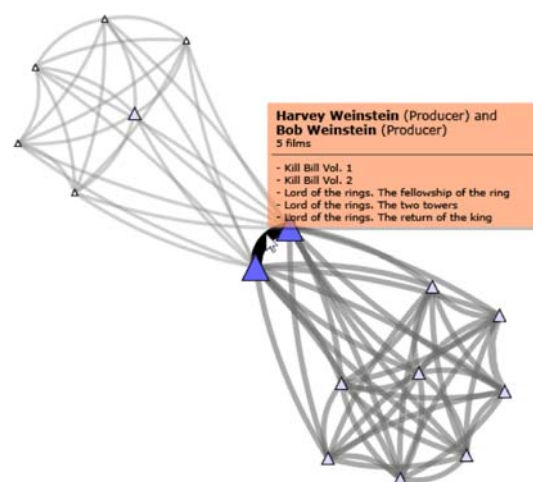


Fig. 12 Network visualization (MedioVis, see [45])

different movies. We therefore need more specialized views. In MedioVis we use a network visualization that can map not just actors, directors, etc. but also content tags onto the network nodes. The nodes are then connected to each other via edges that represent the corresponding movies. We used the Fruchterman-Reingold layout algorithm [14], which tries to group nodes spatially close to each other where those nodes are connected several times. It is now easy to see two clusters of people working closely together by identifying "linking points" (see Fig. 12). Via tooltips we can see that the Weinstein brothers are that linking point and the two groups are people who worked at either the Kill Bill movies (upper left) or the Lord of the Rings movies (lower right).

To view data along a temporal dimension we suggest either the HyperScatter (with time as the x -axis) or the Parallel Bargrams visualization (see Figs. 6 and 9). The latter provides the user with not only the temporal distribution of the information objects but also the inter-relationship with several additional attributes. For example, we can see whether the budget for movies has changed over the last 10 years.

Another approach is to visualize the relationships between different dimensions. Fig. 13 shows a geo-temporal visualization linking the geographical and the temporal dimension. In this case, the temporal relationship between the different filming locations of one director is visualized via a colored line.

In INSYDER we pursued an additional strategy. We visualized the relationship between query keywords and the data, in this case documents. A Tilebar visualization (see Fig. 14) showed each document in segments, indicating which keywords appeared at which positions within the document. In addition to the original concept of [23] we enhanced the tilebar visualization with a coloring to indicate the relevance of different keywords. Especially for very large documents,



Fig. 13 Geo-temporal visualization of filming locations (MedioVis, not yet published)

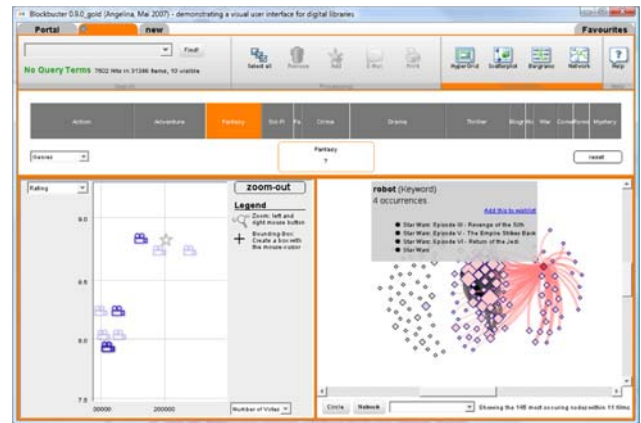


Fig. 15 MedioVis with multiple coordinated views (Bargrams, Hyper-Scatter + Network, [45])

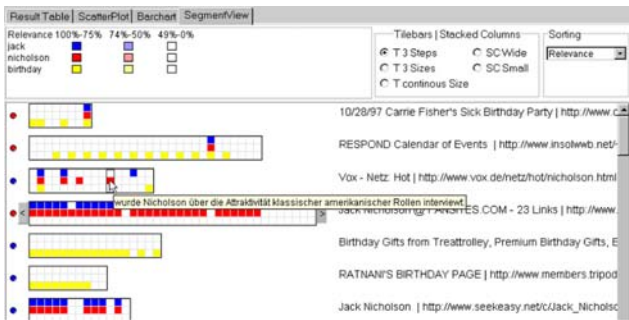


Fig. 14 Tilebar (called Segment View in the screenshot) visualization (INSYDER, see [44])

such a visualization allows the user to quickly identify relevant parts.

Many of these visualizations show their strength best in a particular combination, as also suggested by our Hyper-Grid/HyperScatter study in the previous section. For example, selecting a certain time frame for movies in the Parallel Bargrams visualizations (e.g. everything since the year 2000) is especially useful in combination with a scatter plot. The user can then quickly realize that the selected movies had a very high budget and an above-average runtime. We use a multiple coordinated view approach, with all visualizations being tightly coupled with each other (see Fig. 15) [40]. The bottom line here is that every visualization can act as a dynamic query filter for the other visualizations [53].

In addition, we also integrated the possibility of “pipelining” visualizations. In MedioVis, a toolbar allows a flexible adjustment of the visualizations currently in use. On dragging a visualization into the appropriate area (see Fig. 16), it uses the currently visible information space as input parameter and therefore applies all filter steps that have been carried out before. This supports a sequential filtering of the information space. One must, nevertheless, be aware of the fact that combining several visualizations also makes the system more complex again. Therefore, it is important that simple

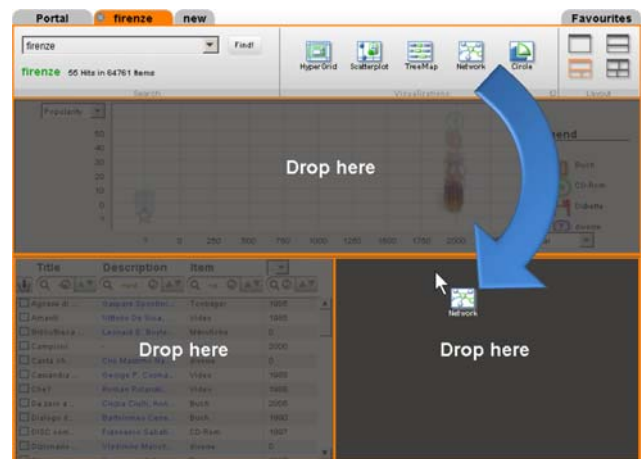


Fig. 16 Drag and drop of a Visualization in MedioVis [45])

and easy configurations are also available. In MedioVis, the user can choose between different layouts that define how many visualizations can be combined simultaneously, starting with one single frame for novice users.

As a final comment on this design principle, we would like to point out that we think it is more useful to integrate fairly simple and well-known visualizations that are probably easier to use. It is still possible to keep the system powerful by enabling an easy and effective combination of visualizations.

3.4 Make search a pleasurable experience

Nowadays, it is difficult for a product to distinguish itself from competitors by pure functionality alone. In many cases the soft factors seem to count even more, with Apple being the often-cited example, at least in the IT business. We use the term user experience to cover both usability as well as aspects such as esthetics, hedonic quality [21], or joy of use. Even though usability engineering offers many methods to ensure a usable outcome, it is quite challenging to

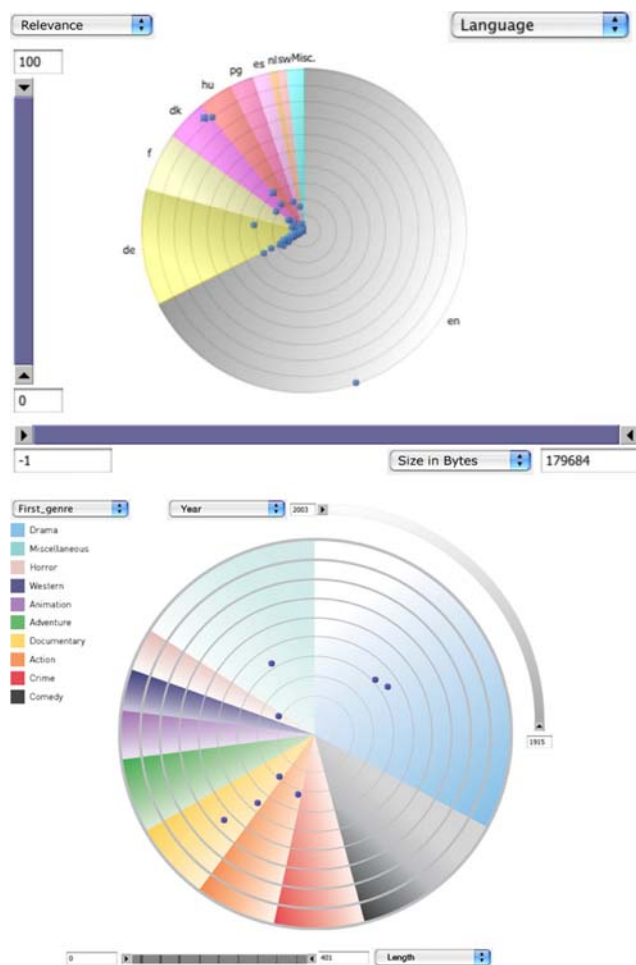


Fig. 17 Top: early CSV, down: redesigned CSV (see [30])

integrate these soft factors systematically. During our MedioVis project, we worked closely together with communication designers. While they redesigned many of our concepts and visualizations, we were able to learn some important lessons. For example, one has to become aware of the fact that every design communicates associations of values and functionalities. And this happens even when the designer of the system had not given any consideration to this matter. Therefore, it is important to not just randomly design and beautify an interface but to also think about this communication aspect. As an example, we will look at the CSV again. In Fig. 17 you can see the first CSV design and the redesign by the communication designers. While the redesign is, in general, much clearer in terms of the layout and the selected colors, the sliders are of special interest. The old sliders were standard JAVA widgets and offered the functionality to dynamically adjust two attributes, one mapped on the radius and one on the angle of the circle. As mentioned earlier, this was not well understood in our user studies. The redesign now addresses this issue by placing the “angle slider” along the angle and by shortening the radius slider to the radius size. They there-

fore communicate exactly what they should: manipulate the angle dimension or the radius dimension.

Another important lesson we learned is that animation and interaction can be fun. When confronted with the zooming capabilities of the HyperGrid, users specifically stated things such as “It is more fun searching with this” and “That is cool”. The LevelTable concept, which provided a similar functionality by switching between levels via a button, never received such comments. We assume that a direct interaction coupled with animation and the browsing functionality of the HyperGrid can be much better at providing a “browsing the shelves experience”, as Hearst puts it [22], than conventional hyperlink concepts.

An overall coherent visual appearance is also an important aspect. In [19] we compared MedioVis with a classic list-based online catalog and used the Attrakdiff questionnaire [21] to measure aspects such as hedonic quality and appeal. The coherent visual design resulted in very high ratings in all dimensions, significantly higher compared to the list-based online catalog. We therefore think that, apart from all functionality and features, the effect of a high user experience should not be underestimated—or the other way around: if a visual information-seeking system is deficient in making search a pleasurable experience, users might just end up not using it, despite its usefulness in principle.

4 Regard search in a broader context—research challenges of the future

Typically, information seeking is a task that is just one part of a higher-level user activity such as “writing a scientific paper”, “creating a digital album of holiday pictures”, or “providing help to a customer at a help desk”. However, today’s visual information-seeking systems are rather monolithic and do not integrate well into such a higher-level activity. With his framework of “mega-creativity”, Shneiderman introduces an abstract model [49] that describes the tasks of such a higher-level activity. While Shneiderman’s framework is rather abstract, there are other higher-level models of information seeking, such as the one by Kahlbach et al. [27], Kuhlthau [32], or Makri et al. [34], which have been grounded in empirical observations and which are more specific about their individual steps or phases. The latter by Carol Kuhlthau is of specific interest in this context, since it focuses on library usage and is verified by a number of empirical studies.

Kuhlthau regards the task of information seeking in her “Information Search Process” (ISP) as a constructive process, during which every person builds or “constructs” their own image of the domain. Furthermore, she speaks of a highly iterative process covered by six steps (initiation, selection, exploration, formulation, collection, presentation).

During these steps, the user passes through different affective, cognitive, and physical stages. The following example illustrates this process: Imagine students getting the assignment to write a report. They initiate a search (initiation), feel uncertain at first and have vague thoughts about what to search for and therefore try to seek all relevant information concerning the topic. During the exploration of the first results, they feel optimistic and develop an idea (selection). By reading further texts, they come across some information that does not fit to their idea (exploration). They feel a little bit confused and frustrated. After a discussion with their tutor, they try to define a focus point (formulation) to get more clarity. After this step, they feel more confident through a better sense of direction. Their interest increases, and they now seek for more pertinent information, collecting these by extracting relevant aspects (collection). When enough information is gathered and the predefined time seems to run out, they stop searching and start formulating the report with the inspiration of the collected information (presentation).

When comparing the presented design principles with such a complex and long-term process, we see that we mainly support the user during specific activities in the initiation (support various ways of formulating an information need), selection (integrate analytical and browsing oriented ways of exploration), and exploration (provide views to different dimensions of an information space) phases. However, the latter three phases of formulation, collection, and presentation are difficult to address without taking into consideration the social context as well as the application context, meaning which applications have to be used together in the collection and presentation phase. Nevertheless, we think that future information-seeking systems should try to integrate and support these activities better.

For the formulation phase, Kuhlthau ascribes an important role to the search mediator, in this case a domain expert, for both the search and the research topic. Such a mediator can intervene in different phases of the search by addressing the user's different emotional stages as well as their specific information needs. We believe that collaborative activities with peers should also be regarded in this phase, since creative work is hardly an individual activity. In today's software, chat functionality or message boards often serve as a collaboration facilitator. However, future systems could also try to facilitate face-to-face collaboration, e.g., by allowing more than one user to interact with the system simultaneously. The last two phases are mainly supported by third party software, for example, a text editor to write up the important findings during the search or in the example above a presentation software to prepare the final outcome of the activity. However, this is often a tedious work, requiring interacting with different interaction styles and switching between applications and the operating system. One might even argue that the basic WIMP concept of today's operating systems makes a better

integration difficult or even impossible. In the following section, we would like to outline how we are trying to integrate these activities better within our visual information seeking systems of the future.

5 The ZOIL-integrated digital work environment

The need for an integrated search spanning different applications and data sources during real-world higher-level activities has been widely recognized. For example, desktop search engines like Google Desktop or Apple's Spotlight were quickly adopted by the users, illustrating the key role of search in today's knowledge work and personal information management activities. However, further improving such information seeking systems, e.g., by integrating visualization components as suggested in this paper, is only a first step toward more integrated work environments. These work environments will better support higher-level user activities by overcoming the inherent information and application fragmentation within today's predominant "desktop metaphor" user interface. While the desktop metaphor of today's operating systems was originally meant to unify applications and information, our PCs, laptops, smart phones, or PDAs are packed or even bloated with a multitude of non-interoperable specialized applications and websites which carry out the actual work. Most of these use incompatible storage formats and inconsistent interaction models (e.g. desktop GUI applications versus hypertext-driven web applications [37]) which have further hollowed out the role of the desktop as a unifying work environment [24]. In reality, content and functionality are scattered over dozens of applications, websites, storage formats, interaction models or devices with each one posing an individual challenge to the user's cognitive skills. This often leads to the necessity for workarounds and to a destructive degree of complexity and "information fragmentation" [29]. As a consequence, searching remains to be a transient and demanding process which is still not integrated seamlessly and naturally into the higher-level user activities.

Raskin [43] has identified this critical weakness of today's "mazelike" interface as one of the main problems standing between current technology and tomorrow's "humane interface". He regards "fundamental changes in the design of human-machine interfaces" as inevitable, since "nothing less will do". The prospects of such a fundamental change have led researchers to suggest designs for the "integrated digital work environments" of tomorrow which go "beyond the desktop metaphor" and open all new perspectives for personal information management [28]. The goal is to design a general-purpose interface, suitable for many different devices which unifies all kinds of content and functionality under a consistent interaction model while leaving the user the

possibilities to establish own workflows, data structures or views on the information space. With regard to this argumentation, we propose the Zoomable Object-Oriented Information Landscape (ZOIL) user-interface paradigm as a visual work environment that could provide this seamless and natural integration of search and information management during higher-level user activities. We will briefly outline the concept of ZOIL before addressing how such an environment might provide better possibilities to address the afore introduced search phases of formulation, collection and presentation.

As an application- and platform-independent concept, ZOIL is aimed at unifying all types of local and remote information objects, together with their connected functionality and mutual relationships, in a single visual workspace under a consistent interaction model. This visual workspace is named the “information landscape” and can be explored by the user by performing zooming and panning operations (see Fig. 18). Within ZOIL, all information objects are organized in space and scale to tap “into our natural spatial and geographical ways of thinking” [41]. All information objects (e.g. objects in a digital library, files and folders on a hard disk, mails in a webmail account, dates in a web calendar, the users of a social networking website) appear as visual representations in the information landscape. Unlike in today’s desktop metaphor, this landscape is not limited to the visible screen size but resembles a virtual canvas of infinite size and resolution (as known from [41,43]). All objects and their connected functionality can be accessed by panning to the right spot in the information landscape and zooming in. ZOIL, thereby uses semantic zooming which in this case means that the geometric growth in display space is not only used to render more details, but also to reveal that content and functionality which is of most use to the user. If the user zooms into more complex objects like documents, drawings, or spreadsheets, they become editable on-the-spot without the need to open a dedicated application window (see Fig. 18a–c). Thus, the available functionality is always coupled with the information object itself as it is proposed by object-oriented user interface design (OUI) as discussed by Collins in [10] and inspired by Raskin’s [43] vision of the “Humane Interface” (see Fig. 19).

Zooming out of the information landscape leads to a decrease of display space. The visual representation of an information object gradually collapses to an icon or glyph. Eventually, an information object is represented as one single remaining pixel. Together with the neighboring pixels, this pixel can then be perceived as a cluster or a part of an overview visualization aggregating a large amount of objects. In Fig. 18a information objects from different sources are grouped in different visual metaphors, for example, a map for displaying geographical relations or a table-like HyperGrid visualization (both based on the objects’ metadata) or

visual clusters of semantically related documents (based on content analysis or manual spatial assignments by the user). An information object might appear in either one of those, providing the user with different ways to recall the position of an information object. Thereby, navigation as a strategy of search is now supported intrinsically by zooming and panning operations. The graphical representation of objects as well as the spatial organization further facilitates browsing strategies, since users are not forced to think in abstract information structures, but can use visual clues and layouts as means of visual-spatial orientation. Heterogeneous information objects are integrated in a coherent way by using a common set of metadata attributes and are simply represented as objects of different classes (e.g. mails, photos, persons, documents). By drawing a bounding box, the user can create portals [41]. These portals provide advanced search and filtering options of the underlying subset of the information space (see Fig. 18f). Users can assign different modes of visualization to such a portal to choose the visual representation most appropriate for the task at hand. This portal approach also provides better ways to explore heterogeneous data in different ways, as different visualizations can be assigned to the same data. This resembles the multiple coordinated views and pipelining concept presented in Sect. 3.3. A dedicated search portal is also constantly provided to facilitate classical keyword searching. Unlike traditional seeking systems, an active search portal becomes an object in the information landscape itself, providing the functionality to refine or process the search results using the portal approach or to store and spatially manage search results for later use.

To illustrate how the collection and presentation phases of the Kuhlthau model are supported by this environment, imagine the following scenario: A user is currently working on a journal article. She has zoomed into this document enabling her to directly access text-editor functionalities (see Fig. 18a–c). While writing, she suddenly realize that she needs some information from the web about the topic of “information visualization”. She accesses the search field on the lower right and starts a search, for example, by a simple keyword search. Immediately, a result list pops up, adjusting dynamically to every keystroke and offering a first clustering of the results to increase the perceivability (see Fig. 18d). This result list or even parts of it (e.g. a certain group or object) can now be dragged onto the information landscape (see Fig. 18e) and as soon as it is dropped it transforms into a portal (see Fig. 18f). This allows the user to change the visual representation of the search results (e.g. choose the HyperGrid visualization as in the example), apply some filters or refine the search. Besides, the user is now able to link this search portal to their current working document. A search is therefore no longer a transient action that is often difficult to repeat but rather a persistent artifact of a creative work process. In

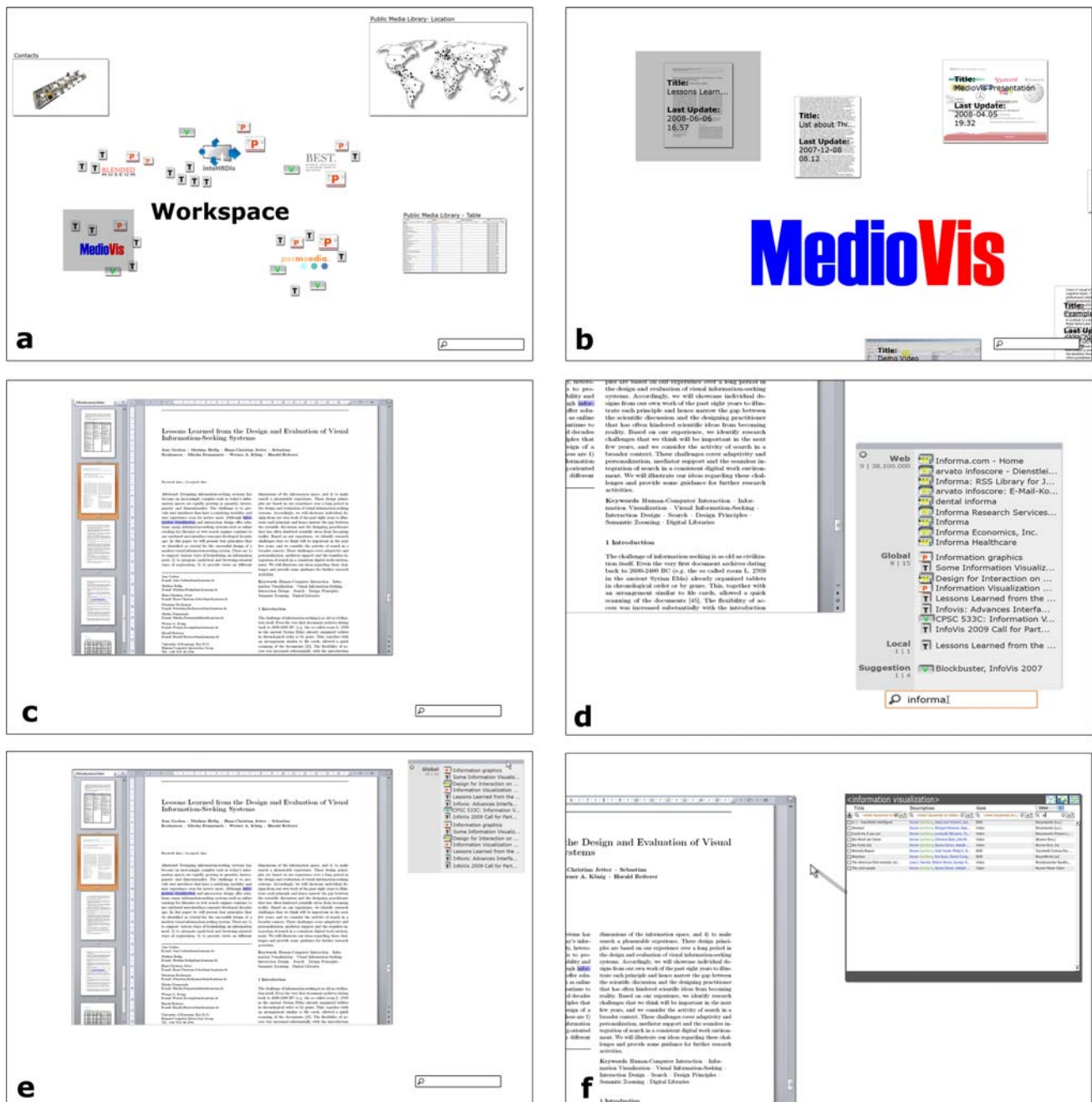


Fig. 18 ZOIL UI Paradigm, **a** Information Landscape overview, **b** Zoom into region—semantic zooming, **c** Detail view on document, **d** Starting a search, **e** dragging the result list onto the information landscape, and **f** by dropping the result list transforms into a portal with adjustable visualizations as well as the possibility to place the object anywhere on the information landscape

a similar manner, the whole information landscape can be individually organized, resulting in a personalized workspace that directly inherits a visual information-seeking system.

This ZOIL approach is also the basis for our vision of a collaborative work environment. In the context of digital libraries, we pursue the vision of a blended library, which

combines and merges physical and virtual interaction. Thereby, the physical library reclaims its role as a place of real-world collaboration by providing a physical work environment augmented with the power of ubiquitous information technology, such as interactive public walls, group interaction tables or handheld devices (see Fig. 20). We

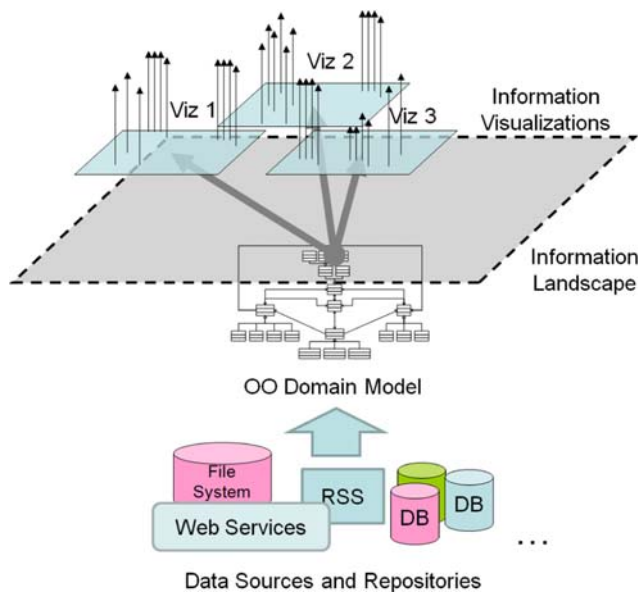


Fig. 19 Domain model and data sources of a ZOIL-based UI

believe that the ZOIL approach transfers well to these different devices and form factors and can provide a consistent interaction design and multi-user support throughout the blended library, facilitating collaboration as well as providing an integrated and natural environment for creative work.

6 Conclusion

While information spaces are growing rapidly in terms of their quantity, heterogeneity, and dimensionality, visual information-seeking systems have to address this situation with more expressive and better-to-use visualizations. Based on our experience from a long period of designing and evaluating visual information-seeking systems, we have therefore presented four fundamental design principles as guidance for designers and developers. These principles are based on the lessons we have learned and we have illustrated them using concrete design solutions from our projects and their discussion. In particular, different search strategies should be supported simultaneously, and different views on the various dimensions of the data have to be provided. Moreover, system designers should try to create a visually appealing esthetic design that correctly communicates the system's functionality to the user. In addition, we are convinced that future visual information-seeking systems will have to consider search in the broader context of their users' higher-level activities. Future research should therefore focus on providing a user interface that integrates search seamlessly into the larger process of knowledge generation and publication. By introducing the ZOIL paradigm, we have outlined a promising design for such integrated work environments. Furthermore, possibilities for providing ways to contact and collaborate with human mediators—not only in a virtual but also in a physical and collocated manner like in the “blended library”—have

Fig. 20 Our vision of a blended library integrating different devices and form factors using the same underlying interaction paradigm (ZOIL) and facilitating face-to-face collaboration. **a** Cube-Wall, **b** TV-similar setting with remote control access, **c** collaborative multi-touch table



been identified as increasingly important and should therefore move on top of our community's research agenda.

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