# Visual Document Exploration with Adaptive Level of Detail: Design, Implementation and Evaluation in the Health Information Domain

L. Shao[1,2], S. Lengauer[1], H. Miri[3], M. A. Bedek[4], B. Kubicek[4], C. Kupfer[4], M. Zangl[4], B. C. Dienstbier[5], K. Jeitler[5], C. Krenn[5], T. Semlitsch[5], C. Zipp[5], D. Albert[4], A. Siebenhofer[5,6] and T. Schreck[1]

[1]*Institute of Computer Graphics and Knowledge Visualization, Graz University of Technology, Austria*

[2]*Fraunhofer Austria Center for Data Driven Design, Austria*

[3]*Carnegie Mellon - KMITL (CMKL University), Thailand*

[4]*Institute of Psychology, University of Graz, Austria*

[5]*Institute of General Practice and Evidence-based Health Services Research, Medical University of Graz, Austria*

[6]*Goethe University Frankfurt, Germany*

*l.shao@cgv.tugraz.at*

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Abstract: Documents typically show a linear structure in which the content can be accessed. However, linear reading is not always desired by users, nor is it the best presentation way, as information needs may be developing or changing over time, and users would thus want to extract the relevant information by navigation and search. Therefore, reading with adaptive focus and level of detail is needed. This is of utmost importance in the health information domain where patient conditions and resulting information needs may evolve in different directions over time. We report on the development of a visual document exploration system which supports navigating a document at different levels of aggregation, from topic overview (high-level) to keyword occurrences (mid-level) to full text (low-level). Our design smoothly integrates the different levels of detail from which the users can choose. The system is designed to track explored topics and use this information to suggest additional content. We evaluated the design and its corresponding web-based implementation through a formative user-study in the domain of diabetes health information. The evaluation confirmed that our design and implementation can raise interest and curiosity, and also allow users to efficiently navigate content of interest.

## 1 INTRODUCTION

Nowadays, Consumer Health Information Systems (CHIS) are indispensable in modern healthcare and fulfil a myriad of functions. CHIS offer consumers a comprehensive overview of a disease, and particularly address general knowledge of health-related topics, their effects and courses, as well as interventions to maintain or restore health. They also enable the early detection, diagnosis, treatment, palliation, rehabilitation and follow-up care of diseases and associated medical decisions, care and coping as well as daily life with the diseases (Arbeitsgruppe GPGI, 2016). Usually, CHIS are provided statically and linearly, i.e., the same medical content is presented to everyone with the same structure. However, patients vary regarding previous knowledge, information needs and health treatment situations, e.g., depending on gender, age, personality, perception, etc., and thus a linear reading may not be the best solution for extracting relevant information for everyone (Bunge et al., 2010). Therefore, an adaptive and interactive visual CHIS is needed that supports document exploration with adaptive focus and level of detail views.

Our main research objective in this work is to develop novel concepts for advanced, interactive, adaptive, and visual CHIS (called A+CHIS). We are focusing our research on the case of Type 2 Diabetes Mellitus (T2DM) because the disease is complex, highly relevant to public health, and its topicality of contents is changing over time, as a result of new groups of drugs, availability of expertise, flexibility in treatment, improved patient education, as well as sustained follow-up practices and screening for its complications. However, managing T2DM is still a difficult and time-consuming task, as it is common, serious, and under-treated. Therefore, it is considered a major challenge to healthcare services and requires adaption of patients and therapies, hence the affected groups have a constant need for information (Standl et al., 2019).

In this work, we introduce a visual document exploration system, including multi-dimensional adaptivity for health information consumers, aiming for a better understanding of the medical content by combining close and distant reading approaches. To this end, we propose a multi-level text aggregation approach, which supports document navigation from a high-level (topic overview) to a mid-level (topic/keyword occurrence) and a low-level (full text and keyword highlighting). Our idea is that a flexible system allows the user to efficiently navigate a document, overview the content, find specifics of interest, and hence follow an efficient information perception. In our design, we set out to make use of well-known document visualization approaches which are tailored and integrated in an efficient system.

To visualize the high-level structure of a document, a dynamic table-of-contents is employed that represents sub-chapters by means of a Word Cloud containing keywords that are pre-generated by a topic-modeling approach. We use a visual navigator based on tile-bars to link high-level structures with mid-level document information. The visual navigator shows topic occurrences within the underlying document and allows users to quickly explore the content by text snippets. We conducted a user study to characterize the usage behavior of health information seekers adopting our approach. We show the usability of our system by comparing linear reading with our multi-level approach.

The main contributions of our work include: (i) a visual document exploration system for health information on T2DM, (ii) a multi-level text aggregation approach, including three levels of aggregation, and (iii) a holistic formative evaluation of our interactive system with a user group.

# 2 RELATED WORK

Our work mainly relates to the field of document and health visualization.

## 2.1 Document Visualization Techniques

One popular and widely-used visualization technique for text data is the Word Cloud representation (also known as Tag Cloud). This visualization technique is a distant-reading technique (Moretti, 2005) that presents a visual overview of text collections by using different type sizes for frequent, or otherwise deemed important, words (Heimerl et al., 2014). Distant-reading techniques for textual data allow users to approach literature in a completely new way. Instead of reading texts in the traditional way, i.e., linear reading or so-called close-reading, the focus of distant reading approaches is to count, to graph, and to map textual data by a visual representation (Jänicke et al., 2015).

Over the last years, much research has been conducted on Word Cloud visualizations. For instance, WordBridge by (Kim et al., 2011), utilizes graph-based visualization techniques to connect several groups within a Word Cloud with information-rich edges. Moreover, other Word Cloud extensions exist that focus on semantic contour lines (Wu et al., 2011) and images (Gu et al., 2017). In our work, we rely on traditional Word Clouds to foster distant-reading within single documents.

For larger document collections, explorative systems such as (Görg et al., 2013) and (Isenberg et al., 2017) can be used, which consider further document features (e.g., metadata information or co-authorship). Another interesting approach to visualizing large document collections is the Document Cards concept by (Strobelt et al., 2009), which represents the document's key semantics by using a mixture of images and important keywords. In order to visualize explicit term distribution within a document, Tile Bars (Hearst, 1995; Keim and Oelke, 2007) may also be used. Tile Bars is a compact pixel-based visualization technique which simultaneously reveals the relative length of a document, the relative frequency of one or more query terms, and their distributional properties with respect to the document. In this work, we utilize a Tile Bars representation to display the relative frequency and distribution of terms from a Word Cloud.

## 2.2 Data Visualization in Health Care

Data visualizations are becoming increasingly important for medical applications, e.g., information on medical diagnostics, treatments, and health. Electronic health records enable novel visualization applications for patient data (Rind et al., 2013). In the current survey of (Wang and Laramee, 2022), more than 40 papers in the core of visualization of electronic health record data are identified. For example, the LifeLine system was among the first to visually represent patient treatment histories and support interactive exploration (Plaisant et al., 1998). For instance, (Cao et al., 2010) used linked Word Clouds to support multi-faceted data analysis of diseases such as diabetes. By using linked Word Clouds, they visualized cluster connections between T1Dm and T2DM. Furthermore, SolarMap (Cao et al., 2011) is a visual analytic technique for visually exploring topics in multi-relational data. It combines a labeled contour-based cluster visualization with a radially-oriented tag cloud.

## 2.3 CHIS

Within the scope of this work, we performed an explorative search on currently available CHIS on T2DM in different media sources (websites, digital documents, print media, apps, videos) and focused on existing elements by which users can adapt the presentation and their use. We found that the possibility to do adaptations in currently available CHIS is only used to a limited extent. We could not identify any adaptive elements in print media, digital documents or videos. Adaptations were only provided on websites and in apps, and mainly concerning the type of presentation, such as adjusting the font size and font color. In some CHIS, it was also possible to select different languages or a read-aloud function for the text (Government of Canada, 2022), (Bundesministerium für Gesundheit, 2022). In addition to these more general adaptive capabilities, only a few CHIS provided adaptations of personalized and relevant medical information. The adaptation mechanisms pre-filtered medical information or specific chapters based on a previously generated user profile representing the current diabetes related situation (British Diabetic Association, 2022). Most CHIS provided a usual table of contents with or without hyperlinks to corresponding chapters. Additionally, some CHIS used links in the text or cross-references to other text passages or chapters. No CHIS in our sample of T2DM used a visual document exploration system with multi-dimensional adaptivity for health information consumers.

# 3 NEED FOR A+CHIS

As mentioned in the previous section, only a few CHIS on T2DM are either *interactive*, *adaptive* and/or *personalized*. The wide range of information sources (brochures, websites, medical doctors, etc.) and the diversity of topics (such as symptoms, treatments, nutrition, etc.) might be overwhelming for medical laypersons. The knowledge domain of T2DM is complex and comprehensive, and thus, characterized by high *intrinsic cognitive load* (Sweller, 2005). Information seekers tend to apply heuristics and cognitive biases at every stage of information processing when confronted with such complex situations. Cognitive biases, mis-

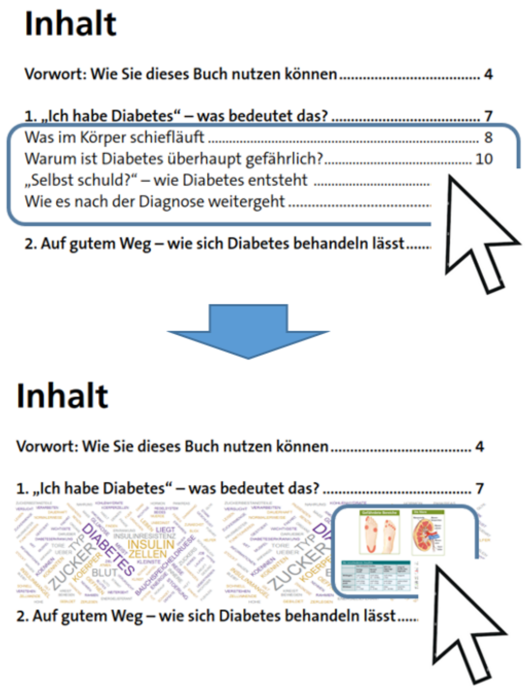


Figure 1: Our design concept allows to smoothly switch from the Table of Contents as the highest level of abstraction, to the subsections (top) to the content aggregation (bottom) using word clouds and images.

conceptions and believing in myths about T2DM may have severe health-related consequences. An *interactive* CHIS has the potential to (i) track behavioral patterns and explicit feedback of consumers, (ii) interpret these indicators in terms of certain cognitive biases (e.g., the confirmation bias), and (iii) intervene if necessary (e.g., by suggesting other pieces or sources of information). An *adaptive* CHIS can ensure that the consumer is neither too bored nor too overwhelmed. Providing information units for which the consumer is just ready to read, understand and learn, reduces the current *intrinsic cognitive load* to a medium level. A *personalized* CHIS has the potential to increase a consumers' personal commitment and thus, help to close the 'intention-behaviour gap' (Schwarzer, 2008), considered as the ultimate goal of a CHIS. To ensure that consumers appreciate to engage with our advanced CHIS, a set of added values compared to more 'traditional' digital CHIS (e.g., a brochure in PDF format or plain webpage), need to be fulfilled: the guarantee of high quality and evidence-based medical information, the reduction of complexity to a medium level, and recommending information units that fit a consumers' information needs. Also, tools and functionalities that help the consumer to get an overview of the knowledge domain, to efficiently answer certain questions, and to easily navigate through different sub-topics should be provided. Formative evaluation activities (Section 5) ensure that such performance goals will be fulfilled.

# 4 ADAPTIVE DOCUMENT EXPLORATION DESIGN

Our proposed document exploration concept supports various degrees of visual granularity, ranging from rough abstraction of the document as a whole, to section and sub-section headings, to word clouds, topic models, and down the original full text content (Figure 1 and 2). To this end, we designed a set of interlinked sub-systems addressing different levels of detail. These components are interconnected via user interaction, allowing for an unintermitted exploration process. In the background, we track user interactions to determine which parts of the content have already been visited and consumed by the user. This information is also displayed to the user in order to indicate which information has not yet been scrutinized.

The components as well as their relations are illustrated in Figure 2. Next, we provide in-depth details on how they are implemented in our prototype.

**Table of Contents.** For the outermost level of visual granularity (document level) we provide an interactive abstraction of a document's Table of Contents. To this end, we present the user with a view showing the main section headers (Figure 1 and 2①). Upon clicking such a header, the respective section is expanded, illustrating the section's content with an abstraction loosely following the *document card* design concept (Strobelt et al., 2009) i.e., different visualization techniques are used to display the textual and visual contents.

For the former, we use a Word Cloud visualization – an established visualization method for encompassing texts – while an Image Slider is used for the latter. On the very left-hand side of a section container, we additionally display the section's subsections as a further hint on the content. On the right-hand side, the already inspected content is indicated with a 'history' version of the Word Cloud and the Image Slider. Specifically, terms and images are added to these components after they have been reviewed (clicked on) by the user. This history cloud keeps the context of the exploration for the user. Alternatively, it can be used to display non-clicked terms as to suggest content to the user.

**Word Cloud.** To generate the word clouds, natural language processing is used to extract 'significant' terms from each chapter. In this pre-processing step, an input text is initially separated into individual parts (tokenization) and irrelevant words are filtered out (stop-word removal). In the following, the set of remaining words is transformed to its canonical form or dictionary form (lemmatization) and grammatically tagged (part-of-speech tagging). Finally, the Latent Dirichlet Allocation (Blei et al., 2003) approach is used to generate topic models on all nouns. For each chapter, we define 6 topic models that are comprised to different extents (term frequency) by a subset of the chapter's terms. This information is used as a basis for content visualization in the form of a Word Cloud as depicted in Figure 2②. The terms are arranged using the *Wordle word cloud* algorithm (Steele and Iliinsky, 2010). The terms are not exclusive for a topic, but topics can exhibit overlapping term compositions. In the Word Cloud, the individual terms are uniquely displayed for the topic they have the most influence on. A 'toggle-able' legend (Topicbar) at the bottom of the word cloud allows the user to influence the selection of the displayed topics. Upon changing this selection, the word cloud is re-computed and re-drawn. Hovering over a term toggles the *Tilebar* for the respective term above it while clicking it initiates the *Snippets* view. To this end, we track the interactions – how often the user has clicked a certain term – with the word cloud. These click counts are the basis for the so-called *History Word Cloud* on the right-hand side of a chapter visualization where the count determines the size of a term in the cloud. The same hover-and-click interactions as with the 'regular' word cloud are possible with the History Word Cloud.

**Tilebar.** Upon hovering over a term in the word cloud, a Tilebar component is displayed above it which allows the user to efficiently grasp the term's occurrences over the whole document. This visualization is inspired by the *literature fingerprinting* concept by Keim and Oelke (Keim and Oelke, 2007) which shows various document properties in a drilled-down manner. To this end, those real-valued properties are computed for equal-sized text chunks and visualized through an intensity map following the linear structure of the document, i.e., from top to bottom and from left to right. In our case, we show the term frequency for which we use a black-to-white color coding, where white indicates that the term does not appear in the respective chunk, and black for the document-wide maximum occurrence of the term. The Tilebar component can be seen in Figure 2③. The individual blocks stand for the book chapters and the red border indicates from which document chapter the word cloud is. Note that the chapters are arranged from left to right instead of top to bottom since the aspect ratio of this layout is more appropriate for the display above the term. The

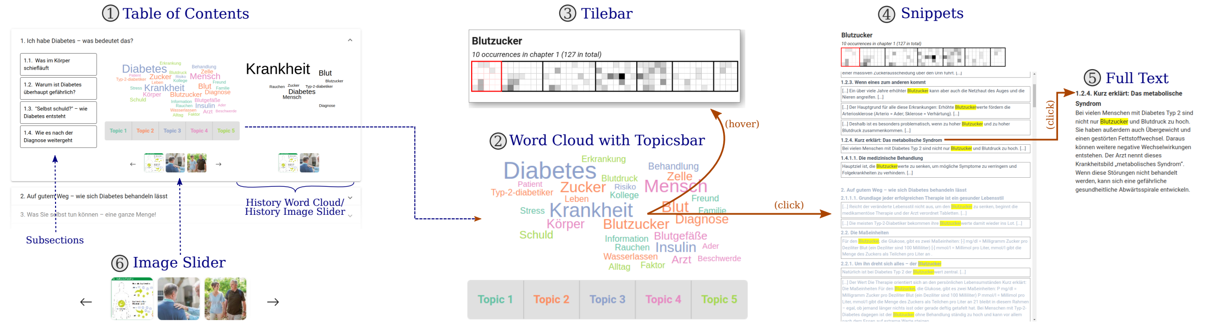


Figure 2: The main components of the interactive visual document system for exploring a German diabetes health brochure (c.f. Section 5). ①Table of Contents, ②Word Cloud, ③Tilebar, ④Snippets, ⑤Full Text and ⑥Image Slider. Different interactions (illustrated as orange arrows) allow a user to navigate from one view to another.

Tilebar allows a user to quickly answer such questions as "does another chapter also cover this topic?" and how frequently is it mentioned.

**Snippets/Full Text.** Upon clicking a term in the word cloud, a *Snippets* view expands on the right-hand side of the interface (Figure 2④). Within this view, all sentences containing the clicked term are displayed with a highlighting of the term. Handles at the beginning and the end of a sentence allow to reveal the preceding and succeeding sentence. Those could be clicked iteratively to display larger parts of the document before and after the found position. Alternatively, the section headers, which are also shown in the snippets view, can be clicked to display a section's whole content immediately (Figure 2⑤).

**Image Slider.** An off-the-shelf Image Slider component is used to display chapters' images (Figure 2⑥). Since we only show three images at a time, we aim to determine an image's relevance in order to sort the list of images, resulting in the most relevant images being shown initially. To this end, we make two assumptions. Firstly, we assume that images without a caption (e.g., scenic backgrounds at the beginning of a chapter) are rather unimportant. Secondly, we split the set of images with captions into two tiers with the first tier being comprised of images showing tables, diagrams, flow charts or convey any sort of structured information, while all the others belong to the second tier. The information whether or not an image has a caption results from the extraction process. We provide an additional image slider to the bottom of the History Word Cloud, showing exclusively the chapter's images which have already been clicked (and thus 'consumed') by the user.

**Implementation.** For the implementation of the prototype, we chose a web stack with a backend written in Python with the *Flask* web framework. The backend is responsible for data management as well as all the text processing tasks, such as the weights computation for the word clouds. The section-wise topics are pre-computed and cached. For the frontend, we chose the *React* web framework as well as the *D3.js* visualization library which offers an implementation of the Wordle word cloud algorithm. The system is available online allowing an easy access for evaluation participants.

# 5 FORMATIVE EVALUATION

The goal of our formative study was to (a) investigate how the system's design and its components are perceived by information seekers, (b) compare it to a linear and static CHIS in document (PDF) format, (c) identify potentials for improvement, and (d) identify future research questions.

As data basis, we used a T2DM information brochure of the German health insurance AOK (Baumgart et al., 2021). The text document is stored in PDF format and contains extensive health information of over 130 pages, including figures, tables and info-graphics. To extract the underlying health information, we utilized the Adobe PDFBox library for full texts and extracted images manually. In a further pre-processing step, we assigned sub-sections and images to the main chapters.

## 5.1 Participants

A total of 12 participants (four females) representing different potential users, took part in the study. Participants were between 26 and 62 years of age ($M$ = 40 yrs., $SD$ = 14 yrs.). They were asked to self-assess their prior knowledge about T2DM ($M$ = 1.00, $SD$ = 1.21), computer and software skills ($M$ = 2.25, $SD$ = .97) as well as previous experiences with visualizations ($M$ = 2.58, $SD$ = 1.24) on a 5-point rating scale (from 0 - very low to 4 - very high).

## 5.2 Procedure

The content of the brochure (Baumgart et al., 2021) was displayed as PDF in Adobe Acrobat Reader and in A+CHIS. A short explanation of basic Adobe Acrobat Reader and A+CHIS functions, such as search functions, was provided to ensure a fair starting point for all participants regardless of their prior experiences. The audio and on-screen activities were recorded. Overall, the study lasted between 60 and 90 minutes per participant.

**Cognitive Walk Through (CWT).** Participants started with a *CWT* (Hollingsed and Novick, 2007) in which they were given pre-defined tasks (e.g., 'In which chapter would you most likely start if you wanted to find out more about blood pressure?') and used them to explore the A+CHIS. This method was used to assess the intuitiveness of the system and how quickly the content can be grasped. Participants were asked to express their thoughts during the tasks (i.e., *think-aloud*). Two parallel versions of 11 CWT tasks were created to compare the information seeking in Adobe Acrobat Reader and A+CHIS. Each participant completed all 22 tasks in a within-subject design, with balanced conditions in terms of system/component order, and parallel versions of tasks.

**Forced Choice.** The *forced choice* required the participants to make choices between the PDF and A+CHIS regarding performance goals of system use. These comparisons were introduced by the statement 'Would you rather use Adobe Acrobat Reader or the A+CHIS to ...', successively followed by the nine performance goals to (a) get an overview of the domain, (b) develop a general understanding on T2DM, (c) search for specific keywords, (d) capture the main content, (e) search for specific images, (f) get an overview of the most important images, (g) efficiently navigate through different topics of the content, (h) get answers to questions you might have in mind, and finally, (i) trace past searches.

**Semi-Structured Interviews.** Last, *semi-structured interviews* enabled targeted inquiries about users' opinions of the system, such as usefulness or appeal. Examples include 'How helpful do you find the various components?' and 'How much does this interactive system encourage you to explore further content?'

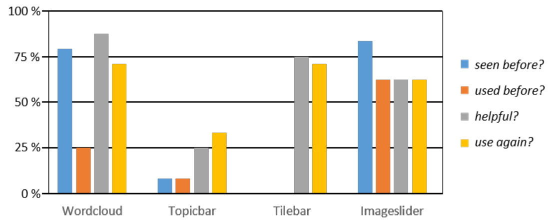


Figure 3: The global evaluation.

## 5.3 Results and Discussion

**Global Evaluation.** In the course of the semi-structured interviews, participants were asked if they had already seen or used a (i) Word Cloud, (ii) Topic Bar, (iii) Tile Bar, or (iv) Image Slider prior to the session. In addition, they were asked if the components were considered as helpful and if they would like to use them again. A 'yes-answer' has been coded as '1', a 'no-answer' as '0', and indifference as '0.5'.

As indicated in Figure 3, around 3 out of 4 participants have seen a Word Cloud or an Image Slider before, no participant has seen a Tile Bar and only one a Topic Bar. The Image Slider has been used most often before (ca. 63%). More than half of the participants found the Word Cloud, the Tile Bar and the Image Slider helpful and would consider using them again. Only around 1 out of 4 found the Topic Bar (in its current form) helpful and would consider using it again.

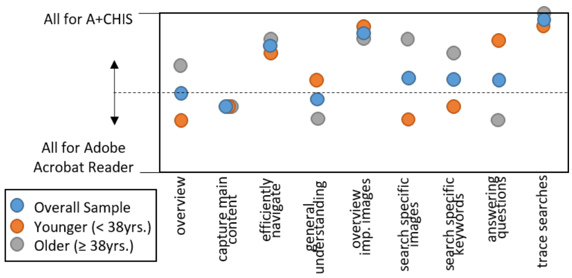


Figure 4: The forced choice results with respect to performance goals.

**Performance Goals.** The results of the forced choices are shown in Figure 4. The potential performance goals in information processing have been sorted from left (more abstract) to right (more specific). A '+1' was added if a participant chose A+CHIS, a '-1' in case of the Adobe Acrobat Reader and '0' for an indecisive choice. Thus, the ordinate ranges from -12 (all participants chose the Adobe Acrobat Reader) to 12 (all chose A+CHIS). Figure 4 shows the values for the whole sample (blue circles), for older participants ($n$ = 6, $\geq$ 38 yrs., grey circles) and for younger ones ($n$

= 6, < 38 yrs., orange circles). Taking into account that A+CHIS 'competed against' the well-known Adobe Acrobat Reader, the overall results of the forced choice are promising. The differences between the two age groups should not be over-interpreted due to the small sample size and should rather be considered an avenue for future research. The resulting overall values for the nine performance goals are either close to the horizontal 'middle-line' (indicating that participants are equally inclined towards A+CHIS and Adobe Acrobat Reader and/or are indifferent) or clearly above, such as for *efficiently navigating* through different topics of the content, getting an *overview* on the most *important images*, or *tracing searches*.

**Non-Linear Content Exploration.** Think aloud and interview data revealed that the system arouses curiosity and invites to further exploration of system features and contents. The main reasons given were the aesthetic color design and the efficient and enjoyable search in the system. Several participants particularly emphasized that the Word Cloud, in contrast to a non-interactive system, motivates to engage with the content further via making interesting terms visible. However, some participants did not yet feel they had sufficiently figured out how the system works to effectively explore the content. In particular, the lack of a familiar linear structure made it difficult for some participants to maintain an overview of the content. While these participants were generally open to exploring the content, they may have needed more support for using the current A+CHIS.

# 6 OVERALL DISCUSSION AND CONCLUSION

Our design allows users to seamlessly navigate the content of a document and change the visual representation and level of detail on the fly. Our approach makes use of well-known visual analysis techniques (word clouds, topic models, tile bars, and keyword search). It is useful for users who would either prefer to follow a traditional linear document navigation and also move non-linearly between content and detail. To the best of our knowledge, there are few empirical studies comparing the cognitive and motivational aspects of using document visualizations such as tile bars and word clouds, with those of linear document readers like Adobe PDF viewer. Our evaluation is a first step that confirmed our concept could heighten interest and raise curiosity, which also allows users to more efficiently navigate content of interest by a distant-reading approach.

Our design allows following both the edited content of a given document (supervised structure) as well as an automatically computed topic models (unsupervised structure). In our study, users did not seem to make great use of the topic model structure. This may be in part due to them not being familiar with topic models, but also difficulties to make sense of topics comprised by lists of keywords. Recent studies have investigated the impact of word clouds for topic understanding (Smith et al., 2017) and keyword summaries (Felix et al., 2018). It turned out that the main advantages of word clouds lie in speed (e.g., recognizing most frequent terms) while disadvantages may arise in numeric encoding and for larger sets of keywords.

A second main element of our design is its observing of the users document exploration. Specifically, we track which keywords have been hovered and selected. This is considered important *information provenance* data, which, in our system, can be used in two ways. First, a history word cloud shows which topics have been already explored. Second, a word cloud of under-explored keywords can be created to motivate the user to explore unseen content. The latter is an important functionality for content recommendation, and possibly mitigation of cognitive biases or harmful pre-conceptions. Our evaluation is a first step in this regard. Future work should look for the specific advantages which aggregated document representations can offer, but also possible misunderstandings which can occur due to the highly aggregated nature of some of the content presentations.

Document visualization techniques provide an amplitude of opportunities for improved support of information seeking tasks. We presented a document exploration design, based on the idea of allowing users to seamlessly navigate document content at different levels of visual abstraction and detail. We made use of established document visualization techniques and applied our design to the T2DM information use-case. We evaluated our implemented system by performing comparison against a traditional document reader. The results are promising in showing that our approach motivates content exploration and is easy to learn. We also presented a concept for possible automatic adaptation of main display parameters, which could provide opportunities to support specific information needs and visualizations as well as reading preferences. In future work, we intend to research automatic recommendation and develop adaptation methods based on the current system.

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