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TagVis: a Visualisation of Relationships Between Tags

Graduation thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Applied Sciences and Engineering: Computer Science

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TagVis: a Visualisation of Relationships Between Tags

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Abstract

The way people navigate the World Wide Web is predominated by the query-response paradigm used by Google and others. The canonical interface is the search mask. Any information need that cannot be expressed with a set of keywords has little chance to be satisfied. One of the first attempts to make information on the web more accessible was undertaken by Yahoo with its introduction of top-level categories. The company provides a huge hierarchy of categories that aim to touch every aspect of human endeavours. Unfortunately, this system could not deal with the complex dynamics and the rapid growth of the web because it adopted the constraint that each website could only be placed in one exact category. A solution to this problem is Tagging which is based on the idea that the user can apply an unlimited amount of keywords on information items for classification. It is superior to the classical taxonomy approach because it allows multi-classification and reflects the user's vocabulary.

Web 2.0 is the current state of online technology as it compares to the early days of the Web, characterised by greater user interactivity and collaboration, better network connectivity and enhanced communication options. Systems like Facebook, Twitter or Instagram form virtual communities that encourage users to create media of all kinds. Tagging is the standard way to bring order into this highly diverse output of information. For instance, Twitter uses it for the creation of channels which bundle tweets around a certain topic or event.

Unfortunately, tagged data is often accessed with the same means as the unstructured web namely querying and browsing. Alternatives exist but fail to make the complex structure of tags visible. The most famous candidate is the *tag cloud* which shows a set of keywords visually weighted by font-size to highlight their importance based on frequency. *tag clouds* are great to show the distribution of tags but completely neglect important other aspects of the data.

This thesis presents a new way to exploit the relatedness and similarity of tags based on Set-Visualisation techniques namely *node-link* diagrams and the *bubble set* technique. By giving the user a hint of orientation our visualisation technique tries to foster an exploratory search behaviour which is more powerful than the Query-Response paradigm. Instead of pure fact retrieval exploratory search promotes the construction of knowledge.

One interesting domain for this purpose is Personal Information Management. It encompasses information from a wide range of different sources and is therefore difficult for sense making. To show that our approach to *tag visualisation* can exploit a real world use-case we developed a proof of concept application for personal information. We based our solution on a User Experience centred design approach which included the creation of several prototypes.

Declaration of Originality

I hereby declare that this thesis was entirely my own work and that any additional sources of information have been duly cited. I certify that, to the best of my knowledge, my thesis does not infringe upon anyone's copyright nor violate any proprietary rights and that any ideas, techniques, quotations, or any other material from the work of other people included in my thesis, published or otherwise, are fully acknowledged in accordance with the standard referencing practices. Furthermore, to the extent that I have included copyrighted material, I certify that I have obtained a written permission from the copyright owner(s) to include such material(s) in my thesis and have included copies of such copyright clearances to my appendix.

I declare that this thesis has not been submitted for a higher degree to any other University or Institution.

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1 Introduction

Nicholas Carr, Author of *The shallows: What the Internet is doing to our brains* argues that modern internet usage deprives us of the ability to think contemplatively [26]. Unlike actionable thinking which objection is always a tangible result contemplation does not serve any reason at first sight. In simplistic terms actionable thinking is always embedded in the following goal directed process:

$$\mathit{Thinking} \gg \mathit{Action} \gg \mathit{Results}$$

Contemplative thinking is a phenomenon that is content with its own activity. Thinking for the sake of thinking. There there is no real notion of a result to expected. The main motivation is a vague appetite for knowledge. One can point on facts which are already established but it is difficult to define something which exceeds the current understanding.

According to Carr, the internet imposes an extreme form of actionable thinking on us which wipes out our ability to immerse in a non goal directed way of thinking. The Google search paradigm resembles strongly the process of actionable thinking in the sense that first, one has to think about what to search for, then the search needs to be executed before one can review the results. The problem lies in the strict separation between the act of thinking and performing actions. First the user needs to establish a set of keywords to be fed in the search mask before she can review the results. It becomes difficult to freely stroll through an information space guided by spontaneous associations because any interest need to be materialise any interest into a search query. The expressive power of this approach is highly limited in the sense that it only allows to ask a well defined question to a close ended problem. Even worse, nowadays, this form of inquiry is not only bound to the web. It underlines all other human activities related to information. For instance, a lengthy not target oriented introduction to a vast topic cannot stand our craving to be stimulated by a stream of new information every minute. Open ended thinking is in danger to be rooted out if the designer and developers of the future do not provide solutions to support it.

Fortunately, in the last decade some research in the field of Information Retrieval took opposition with the attempt to create a new exploratory information seeking behaviour for digital media which relieves us from the need to formulate any search query [67]. Exploration of information is taken literally. The user can move freely throughout the information space with different means such as browsing, orienteering or keyword chaining. Notably, Dörk et al. developed an ideal typical persona which transported the idea of contemplation into the digital domain [36]. The so called Information Flaneur has no precisely defined aim or need when strolling through an information space. They are driven by a stream of spontaneous associations which are automatically established within movements. Simplified, Dörk et al. advocate to view information spaces like vibrant big cites with full of excitements waiting to be discovered.

Figure 1.1: The Flaneur illustrated, wandering around in the city

1.1 Motivation

With the advent of the personal computer and the World Wide Web we are facing a never ending stream of information that often results in the disability to locate relevant information. Already in the past, it was a hard task to organise paper such that we can work more effectively and efficiently. In his highly influential paper *Man-Computer Symbiosis*, Licklider found out that it takes up to 85 percent of our time to find a position to think [64]. In order to develop ideas, theories or opinions, information is crucial for our minds. When we spent more time to look for the right piece of information than to process it, we become less productive. Licklider argued that computer systems can help us to facilitate *formulative thinking* as they now facilitate the solution of formulated problems [64]. He envisioned that computers can free ourselves from cumbersome repetitive tasks in order to use our minds for only creative thinking. Even though computer systems have been widely adopted we still do not exploit the possibilities to store and retrieve information in novel ways. The canonical interface of the web is still the query box followed by a result list of 10 blue links [34]. It is questionable whether order can be brought into this vast information storage with such a simple interface.

One of the first attempts to navigate the web in a more structured way was the website *Jerry and David's Guide to the World Wide Web* [10]. It offered a directory of other websites organised in an hierarchy instead of a searchable index of pages. People were instantly drawn to this way of exploring information because they did not have to make the effort to come up with a query. Instead, they could just move from category to subcategory by relying only on association as guidance. The website became an instant success and grew fast. It was renamed finally to Yahoo in 1995. But with the time the number of categories grew and grew and it was not obvious any more why, for instance, books belong to the category *entertainment* and not to *humanities*.

In general, the hierarchical classification system is derived from physical constraints of storage and the inability to keep in mind several locations of the same object at once [2]. It is impossible to categorise a physical book in more than one category if one only has one copy of it. Even though the same book deals with more than one topic. The hierarchical system is a natural fit for the physical environment because it assigns an exact location for each object. In the digital space physical, constraints do not hold any more. A digital file can be at different places at the same time. But people still use the antiquate system of hierarchies even though it cannot capture multiple dimensions.

One candidate for multi-classification is tagging. By assigning several textual classifiers to an item, a book can finally deal with several topics. Tagging came to fame with the advent of the Web 2.0 and so-called Folksonomies. Systems like Twitter, Facebook, Blogs or Instagram democratised the creation and distribution of content on the web. Social and technological innovation is not driven by large corporate organisations any more. The modern web user is empowered to become producer of media content instead of only consuming it. With this user liberation social media platforms could not afford any more to impose any strict classification systems on the user. Instead, they introduced tagging as novel classification scheme.

1.2 Contribution

As already explained before, tagging is a flexible and intuitive way of organising information. But there are also issues concerning the navigation and search in tagged information spaces. According to Begelman et al. there are only two ways to interact with a tagged information space. First, one can use traditional search and refine techniques. Second, some kind of tag space visualisation can be applied which is often a *tag cloud*. This limited choice highlights one of the key problems of tagging. Even though the de facto standard *tag cloud* visualisation is easy to grasp and provides an overview of tag distribution, it does not take into account relationships between tags.

In practice, there have been attempts to exploit the tag space. For example Viegas et al. identified the importance of pleasing aesthetics to make data analysis more appealing [87]. Hassan-Montero and Herrero-Solana sought for possibilities to improve tag clouds for information retrieval [50]. [88] combined a tree layout with the tag cloud approach to represent hierarchical relations in textual data. Despite the improvements navigation in tagged information spaces is still an issue for many techniques.

Current interfaces for hierarchical classification techniques provide a better sense of orientation. For instance, navigating and exploring the folder hierarchy of modern operating systems (Windows 10, Apple OS X) is still unparalleled. Of course, this is mainly due to the simplicity of the hierarchical structure itself. Nonetheless, the aim of this thesis is to create a new visualisation technique which offers the same affordances in terms of navigation as the hierarchical file system. The design and development will be embedded in the domain of Personal Information because it was rarely subject of exploration as noted by Cutrell and Dumais.

> *One might wonder why people would need to "explore" their own information. An important reason is that it is difficult for users*

> *to unambiguously specify what they looking for, even in their own collections."*[33]

A proof of concept application called TagVis will be developed in the domain of Personal Information (Chapter 4). But the underlying visualisation technique will not be bound to this domain. It makes very few assumptions about the data format. It will suitable to apply on any other tagged data source. Most of the so-called Web 2.0 applications make use of tagging as well. They can be also visually explored with our tool with only minor data preprocessing.

From a technical perspective TagVis relies on novel algorithm to abstract hierarchies from tagged data to facilitate navigation. It is inspired by already existing techniques. The approaches proposed in [3, 78] work well for aggregation visualisation techniques that emphasise the representation of tags but neglect the depictions of the underlying data elements. Our approach suits visualisations that represent each data element directly by a visual surrogate. They are superior to aggregation techniques because they do not need to be coupled with an additional view to browse the raw data. For instance, a tag cloud is pretty limited in functionality when used alone.

The algorithm produces hierarchies which can be used in many ways. For instance, it can be used as additional navigation structure for an existing visualisation. Also, it is useful to simplify highly interconnected information spaces. To wrap up, we will contribute to information visualisation research in two ways. First, a novel visualisation technique for tagged data will be proposed. Second, an algorithm to derive taxonomies from tags will be designed which is crucial for TagVis but can also be used in different contexts.

Finally, we will embed this technique into an application to foster exploratory seeking behaviour in the context of personal information. Thereby, some light will be shed on specific characteristics of exploration in the case of personal information.

1.3 Outline

In order to develop a visual search tool of tagged data we will start from scratch by defining information and its possible states in people's mind and in the physical world. Consequently, the process of cognition is the focus of the next section in which we try to identify the cognitive processes and memory systems relevant for creating knowledge based on information. We then examine how information is actually acquired in the first step. We explain the main motivation to embark on information seeking and also illustrate important information seeking behaviours in different granular levels.

In order to derive concrete user-centred requirements *TagVis* needs to be embedded in a domain. We examine the personal information domain and its relationships to exploratory search. In the design chapter, a visual search application for personal information will be developed. It draws inspiration from open ended exploratory seeking strategies and more directed refinding techniques alike. The *persona* technique will be used to highlight key characteristics of our target users. The resulting design will be evaluated with the *participant observation* [59] technique. The user performs some common refinding tasks. The experiences, opinions and difficulties in using the application will be tracked. Finally, we discuss the graph model on which TagVis is based.

2
Background

In this Chapter, all concepts and research fields are discussed which have special importance for the endeavour to create a visual search tool based on tagging. Starting from a more theoretical and philosophical perspective we discuss the nature of information and its relation to knowledge in general. Then, a light is shed on the *human information behaviour*. Then we argue with how people search primarily information. Secondly, we will examine the role of Information Visualisation in context of searching. The *visual exploration* behaviour is of special importance because it tries to translate the human seeking practices from the physical space into the digital domain by utilising *information visualisation* techniques. Thirdly, the information exploited by search tools is of a certain form. *Tagging* will be discussed in detail and compared to two other candidates in terms the human effort to create such a structure and the degree of expression i.e. how well real world phenomena can be modelled with these techniques. Moreover, a selection of visual metaphors to interface these structures will be covered. Figure 2.1 shows that our research is situated in the intersection of the domains Information Seeking, Classification Techniques and Information Visualisation.

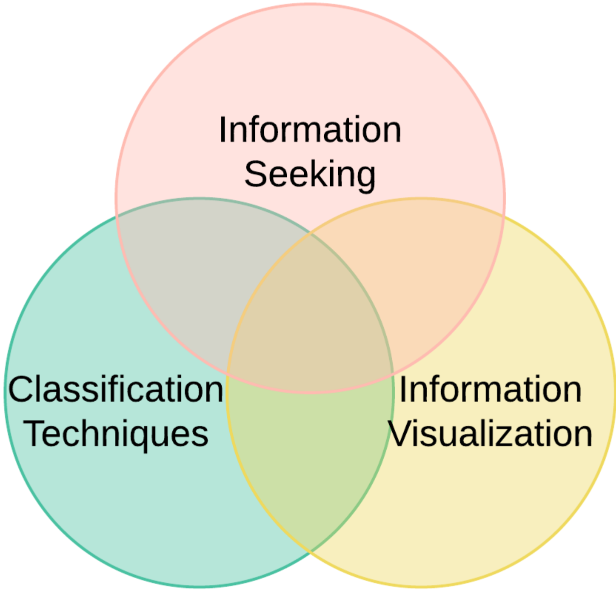

Figure 2.1: Intersection of research areas.

2.1 What is information?

Defining Information is not an easy task. In the last decades, several research areas such as information science, psychology and electrical engineering came up with their very own definition of information to serve their very own purpose. In the latter information is measured on the effect to which degree uncertainty between a sender and receiver is reduced [74]. The two are not tied to be living beings to process information unlike in psychology. There, scholars are concerned how humans attend, encode, store and retrieve information with their cognition. Their notion of information is based on sensory stimuli of the outside world. Therefore, anything what can be perceived consciously and unconsciously is information. Ironically, the science which bears information in its name could not agree on a consensus for a long time as pointed out by Faibisoff [43]. A first proposition was made to define information on an operative level which might not have captured its true nature but permitted to examine the human behaviour in relation it:

> *"Information is a symbol or a set of symbols which has the potential for meaning."* [43]

This definition basically synthesises the both views explained before (psychological and electrical engineering view) because symbols can be anything which is presented to our perception and *meaning* highlights the effect on people's uncertainty. To make matters worse, Buckland identified that information is used for many different concepts in everyday language. He identified three different principal usages for information. Firstly, *Information-as-process* is the act of being informed. It contains communication among people but also deriving information from perceivable objects. Secondly, Information-as-knowledge is the intangible product of information-as-a-process. Finally Information-as-a-thing refers to tangible objects which function as the source for information such as data or documents which can be meaningful. [24].

For the purpose of this thesis, we refer to information as objects which are external to our minds. Information does not need to be tangible in the physical sense. A computer file is as much a piece of information as a real book. For knowledge we use a stricter definition [47] than proposed by Faibisoff in the sense that it only includes information which has a positive effect on the state of knowledge. It can be formulated as follows:

$$K[S] + \triangle I = K[S + \triangle S]$$

The state of knowledge $K[S]$ is changed by some information $\triangle I$ to a new state $K[S + \triangle S]$ where $\triangle S$ denotes the effect of information on the current state of knowledge. Therefore, our notion of information does not include any information which is irrelevant in a particular context of a person. For instance, a person has worked on an article for some time and switches the context to the task of making a tax declaration. Then information from the former becomes useless for the latter. To forecast, one of the hardest challenges for the resulting search tool will be to filter out irrelevant information for a changing user context.

2.2 How to build Knowledge?

In *How to Grow a Mind: Statistics, Structure, and Abstraction* the authors bring up the question how the human mind can form such powerful generalisations, abstractions and causalities from so little data input [80]. The product of complex cognitive tasks such as learning, reasoning or induction which we call knowledge outstrips by far the underlying information which is most often incomplete and flawed. So, how does this gap between rich knowledge and sparse information can be explained?

Already, Plato identified that there is a second source of information needed to create knowledge [32]. Plato called this experience, modern cognitive psychologists speak about background knowledge. Whereas cognitive scientists and machine learning practitioners still struggle to re-engineer the process of joining low level data with high level background knowledge much more certainty exists which kind of information is involved in the creation of new knowledge.

Much more Tulving argues that there are different memory systems for different types of information [84]. The long term memory system can be decomposed into a declarative and implicit memory system. The former is responsible for the encoding, storage and retrieval of knowledge under conscious control whereas the latter resides on an unconscious cognitive, hence it cannot explicitly activated [69]. The long term memory further subdivided into a semantic memory and episodic memory system, as exemplified below.

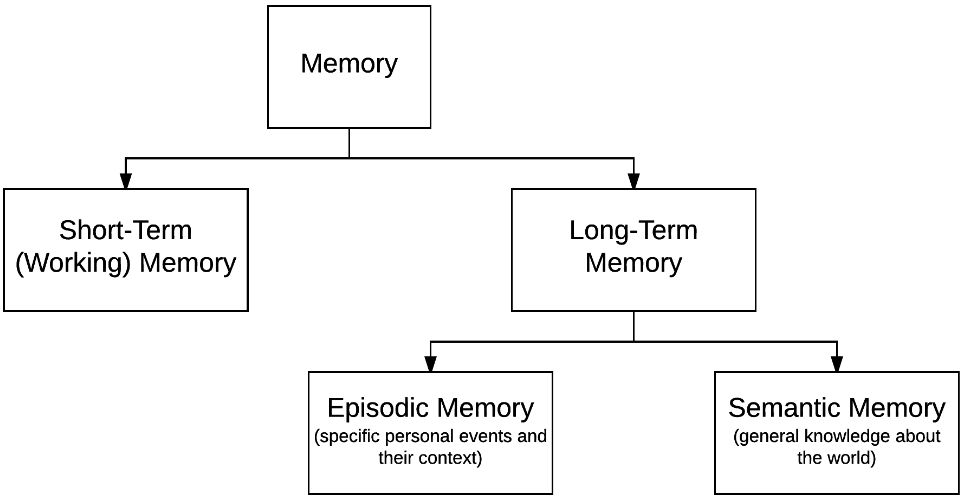

Figure 2.2: Memory types: long term and short term memory system.

The semantic memory system is responsible for registering and storing generic knowledge about the world in form of objects which represent facts, meaning, concepts, propositions or relations [73]. It enables humans to think about real world phenomenons in situations which are decoupled from their direct experience. Contextual factors of objects are only stored when they are relevant for the comprehension of the object itself. For instance, the knowledge that a knife can cause physical damage when not used carefully could be derived from a past accident. But the accident as a context is not saved in the semantic memory, only the resulting knowledge is. Another example is a student who is trying hard to solve a mathematical equation by applying several laws for reformulation. Thereby she is consulting knowledge from the semantic memory. Furthermore, the creation of new knowledge is not tied to any explicit experience triggered by sensory stimuli. It can be solely created by relating existing knowledge in novel ways. This stands in high contrast to the episodic memory system which enables the owner to recall autobiographical events and the associated context in terms of time, places, related thoughts and feelings. These perceptible properties are explicitly stored and serve as cues for later retrieval. For instance, the student's memory of hearing the mathematical laws for the first time at school, several years ago while she was already fed up listening to the boring mathematics teacher for hours, clearly marks a personal experience and therefore is saved in the episodic memory system.

Essentially, the owner of an episodic memory system is able to travel back in time mentally and re-experience a personal event with a high degree of contextual details. It functions as a catalyst for the acquisition of new knowledge of the world in the following sense. First of all, the semantic memory system can access the episodic memories and decouple them from their context. Thereby, symbolic referents to episodic memories are stored. Also, each retrieval from the episodic system can change the underlying knowledge whereas retrieval solely from the semantic systems leaves the knowledge unchanged.

Knowledge from the long term memory can be remembered with a number of techniques [55]. With recall a person can bring back objects instantly from memory without any effort. But recall does not work always, often one has the feeling to know something without being able to recall it. This problem is called *tip-of-the-tongue* phenomenon and can be circumvented by thinking about concepts or past events which are related to the sought information [23]. Thereby, one re-collects the context when experienced or developed the information for the first time. Unfortunately, recollection is a really slow and cumbersome retrieval technique.

On the other hand, recognition is much more efficient. External stimuli such as sounds or images implicitly trigger cues which in turn draw attention to other memory elements. The underlying *spreading activation theory* provides a framework to understand knowledge as memory elements which are connected by some sort of association to form a network. Cues are itself memory elements and function as source of activation. When a cue is triggered, all associated pathways are simultaneously activated and compete in some fashion to retrieve a response [72]. As soon as attention drops from one of the cues the activation of related elements slowly decay. However, the more cues are triggered, the more elements are activated and it is more likely to find the relevant information. In this way, recognition can be understood as externally triggered recollection which happens without any cognitive effort. It must be said that the semantic memory can only rely on semantic cues when the owner retrieves from it. This stands in high contrast to the episodic memory where the stored context can yield many different cue types.

Research has shown that the retrieval rate notably increases when the conditions in which information is learned matches the situation in which it is remembered [86]. In other words, when humans trying to recall information are confronted with exact the same environment where it was acquired the first time, they retrieve by recognition from the episodic memory because a high number of cues are triggered automatically and related to events which might contain the piece of information.

As shown, computer scientists still struggle to simulate the full scope of cognitive retrieval processes. But in order to make the search behaviour more effective and efficient one might try to artificially recreate the user's context in order to provide a sufficient number of cues such that the mind can reproduce the sought information on its own. If computer scientists cannot re-create natural cognitive processes, they can at least provide the user with all necessary information to make the process of knowledge creation easier and faster.

2.3 Human Information Behaviour

In order to understand how people store and access information in their personal collections in particular it is necessary to have a notion of human information behaviour.

According to Wilson, Human Information Behaviour is the totality of actions regarding sources and channels of information [90]. It does encompass active interaction such as the purposeful information seeking in physical or digital environments such as browsing or directed search. Also the passive reception of information which takes place when one is watching a film is considered by Information Behaviour. Besides these more high level behaviours it also takes the direct actions into account applied by the user to access information which can be the use of a mouse to scroll down a big list of retrieved items in a computer system, for instance, or it can refer to the act of physical browsing through a bookshelf. Knowledge is not always the outcome of information behaviour but always desired. Figure 2.3 visually subdivides the three facets of Information Behaviour.

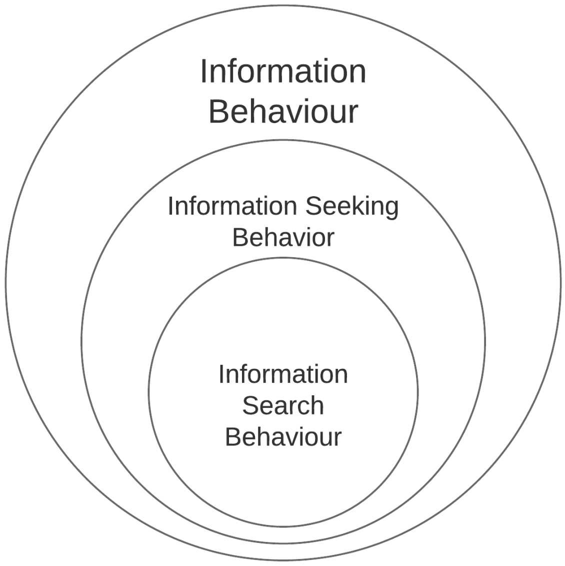

Figure 2.3: Human information Behaviour classification. Taken from [90].

2.3.1 Information Need

The concept of the information need often refers to a perceived anomalous state of knowledge regarding an information problem. For instance a typical example need in the realm of humanities could be expressed as follows:

> *"I'm looking for resources which explain the colour theory of Goethe and Newton in order to derive the differences among art and science."*

This statement can be interpreted as a knowledge gap because there is a mismatch between the current state of understanding and a desired state. In order to accomplish the aim, information has to be acquired and translated to knowledge. Therefore, the information need is the starting point for any seeking endeavour. Furthermore, they can be decomposed into desires and requirements. The former refers to a want for some information resources which is internal to our minds. People express these wants in form of requirements which are used to initiate the information seeking process in some information system (library, database). For instance, the following demand might point to the same desire as the statement mentioned earlier (resources on the colour theories of Goethe and Newton).

> *"I need example literature which highlight the differences between art and science in the 18^{th} century."*

In some cases, differently stated requirements refer to the same desires and in other cases similar formulated requirements might point to completely different desires. One might even imagine that sometimes these desires cannot be expressed at all. Only when the user is confronted directly with the information items they realise that they were looking for them. This phenomenon raises an interesting question namely, *how can you look for something that you cannot make tangible to the information system?*

2.3.2 Information Seeking Behaviour

The first step for building knowledge is acquiring information. In everyday life, people encounter lots of information. To find interesting information at the first place and discover related information is an active area of research. *Information seeking* strives for a human-centred understanding of the search process. In the past, the targeted information was of physical nature and stored in libraries. In parallel, computer scientists were also interested in the search process based on digital information. Unfortunately, until the beginning of the 2000s, they completely neglected the human component and were mainly focused on increasing the precision and recall rates based on an oversimplified query-response paradigm that did not take into account the interactivity among the seeker and the information store [14]. For them seeking was equivalent to the more narrow minded activity of querying. Fortunately, there have been attempts to liberate the notion of information seeking from this simplified static paradigm in digital environments, notable by [19, 67, 37, 81].

2.3.3 Information Seeking Strategies (Browsing, Searching and Beyond)

Information seeking strategies cover the interactive process among the seeker and the information sources. This process is often undertaken in an iterative manner and can be decomposed into techniques which are explained in the next Section.

The two widely used strategies applied in the information seeking process are directed search and browsing. According to Kwasnik the former can be defined as scanning, navigating, skimming, sampling and exploring [61]. Bates acknowledged that browsing is a basic seeking behaviour and not only relevant to information science as it is a natural behaviour and widely used in everyday life as a means to filter out relevant from irrelevant information. She characterises browsing based on [27] as follows. It involves an act of scanning which can be seen as a sequence of sampling and rapidly judging documents. Often, it is guided by an open-ended interest into some domain and not backed by a clearly defined target item. It triggers a set of associations which re-calibrate the overall direction of the information seeking process without much mental work [19]. In the definition she puts the human, mental and behavioural aspects into the focus and not the information source (library, office). Marchionini argues that people browse to gain an overview of an information space.

> *"By scanning a scene or a document, key landmarks and characteristics are identified and used to form impressions of the scene or document and to make analogies to known scenes or concepts."* [66]

Web browsing in information retrieval systems is done by navigating through skimming, scrolling, navigating through HTML documents which are related by some kind of topic and interconnected by references in form of hyperlinks. By doing so the user extracts the gist of each item allowing to make rapid judgement whether the investigated topic is interesting. The act of navigation is an important aspect of browsing, sometimes it is even used as a synonym, but it is not quite same. According to Marchionini, it neglects the cognitive dimension of browsing and is more concerned with the physical movement through information spaces. Therefore, it needs to be considered as a tactic to realise the effect of browsing rather than browsing itself.

Browsing rarely happens as a sole process. Often, it is combined with directed keyword search in a multi-stepped process to gather a set of possible interesting items as a starting points for browsing. Directed Search is concerned with incrementally refining a search query until it meets the information need. By its own it is a much more cognitive demanding activity than browsing because it consists of two distinct phases. First, the information need has to be clarified mentally in order to be translated into a query to finally execute the query and retrieve the results. Directed Search can be also performed in isolation. Then it is used to directly jump or teleport to information targets which rarely succeeds in practice because the user needs to be absolutely certain about her information needs. In general, it is a much more target oriented activity because it tries to find exact answers to a clearly defined questions. The first model that took into account multiple steps in the information seeking process was introduced by Bates and is called *berrypicking*. Thereby, the searcher gathers and learns about the content and consequently changes her information need throughout several iterations. Figure 2.4 shows the evolving search of berrypicking. Users initiate the search with just one feature of a broader topic or just one relevant reference, and move through a variety of sources. Each new piece of information they encounter gives them new ideas and directions to follow and, consequently, a new conception of the query. At each stage they are not just modifying the search terms used in order to get a better match for a single query. Rather the query itself (as well as the search terms used) is continually shifting, in part or whole [19].

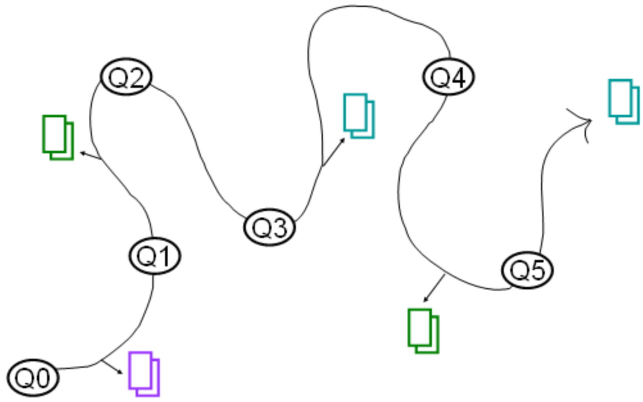

Figure 2.4: The berrypicking model by Bates.

For instance imagine a person who searches for resources of Goethe and Newton to highlight conceptual differences in their colour theories. Thereby, they come along a reference by Wittgenstein who was also interested in the philosophy of perception. Instantly, the person remembers that they took a course on philosophy and Wittgenstein was part of it. Instantly, their attention is drawn to it to skim through the old course material. Thereby, the information need and also the whole direction of the seeking process is changed entirely from Goethe and Newton to Wittgenstein. Building upon the work of Bates, Marchionini embeds seeking strategies into a broader context to serve the aim of information sense making rather than pure fact retrieval. He classified *search behaviour* into three tasks as depicted below in Figure 2.5. He calls the most basic activity *lookup* which is concerned with refining a search query until it meets a static information need. For instance, the search for the birth and death date of Goethe and Newton are typical lookups because the searcher is certain that the number is out there one only has to locate it. On the other hand, learning and investigating searches respect more open ended information needs such as developing a theory of a certain topic or the discovery of knowledge gaps.

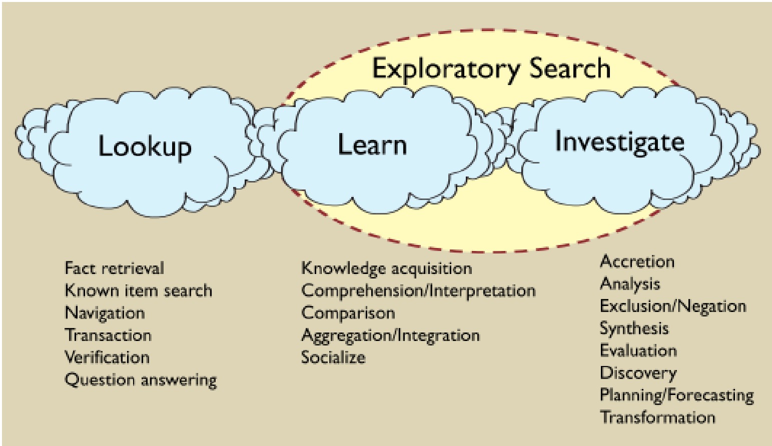

Figure 2.5: Exploratory search activities (Learn, Investigate) versus lookup search. Taken from [67].

Learning Searches rely heavily on cognitive activities such as comprehension or interpretation in order calibrate the direction of search. Investigating searches aim to maximise the recall rate and are less concerned with precision. The three clouds in Figure 2.5 are overlapping because lookup, learning and investigating rarely happens in isolation. A typical search process might be initiated by a lookup which yields an unexpected result which in turn causes an investigating search to find out why it does not meet the expectations.

Their underlying information needs are inherently more complex, fuzzy and shaped by uncertainty because the user has only a vague idea what they are looking for. Conceptually, Marchionini built upon the model of Bates in the sense that the underlying information need gradually transformed throughout several iterations. Within the search process, the user might discover related documents which trigger associations to change the search direction completely.

2.3.4 Micro-Techniques

There are techniques of *information seeking* which operate on a lower level than information seeking strategies. In literature, they are often called *tactics* [53]. They cover direct interaction with information sources and can be composed to realise more complex information seeking strategies. In the following, we will recall the classification envisioned by Ellis [42] and relate it to *tactics* proposed by Thudt et al.. We do so because Ellis explicitly identified stages for starting off and ending a search task.

The first technique *starting* is concerned with the identification of relevant resources as a starting point for the seeking process. Often, this point is chosen in terms of interest, familiarity and the number of references to other resources. As the name suggests, *ending* is concerned with finishing a seeking endeavour and requires that the results are accurate according to the underlying information need.

The activity of *chaining* i.e. linking in the terminology of Thudt follows links of connected documents to gather new ones. It can be performed backwards and forwards. For instance, following hyperlinks in the WWW can be seen as forward chaining, whereas backward chaining in the sense of jumping back from one website to the one which linked to it is not supported by the HTTP protocol.

Scanning denotes the visual skimming through information sources without deeper assessment. It can be best exemplified flicking through the pages of a magazine whereas the attention is only drawn to photos due to the high speed of the movement. In the web, scanning is often used to review results produced by querying a search engine. On the other side of the spectrum, the *assessment* technique denotes the careful and deep inspection of information. It is based on the critical comparison, filtering and selection of two or more resources [81]. Ellis proposes three distinct tactics to achieve the same effect. *Differentiating* is concerned with filtering and selection of information based on noticing differences among them. *Extracting* is the identification of relevant documents or passages within documents and verifying examines the accuracy of documents [42]. As an example, consider an information seeker who found several resources on Goethe which interpret certain key aspects of Goethe's world view differently. In order to spot the differences in detail the seeker reads the documents one by one and highlights key passages. Thereafter, she reflects upon the passages and discard some articles that do not suit the information need.

Last but not least, the act of *querying* is the standardised inquiry of an information system based on a question, a name, a keyword or another point of reference. Therefore, the user needs to transform an often vague information need into specific search terms. For instance, some search interfaces include fields which are obligatory and often the user cannot come up with an input for these particular fields. Performing a sequence of queries is regarded to be the directed search strategy. As can be seen in Figure 2.6, these tactics can be composed in different ways to yield more complex seeking processes which represent seeking strategies as explained earlier. Thudt et al. argued, when information seeking strategies can be translated into a sequence or loop of micro-techniques they can be also used to derive more precise requirements for user interfaces that foster these strategies in the digital space. During the design phase of TagVis, we will come back to these tactics to decompose the overall functionality into these tactics.

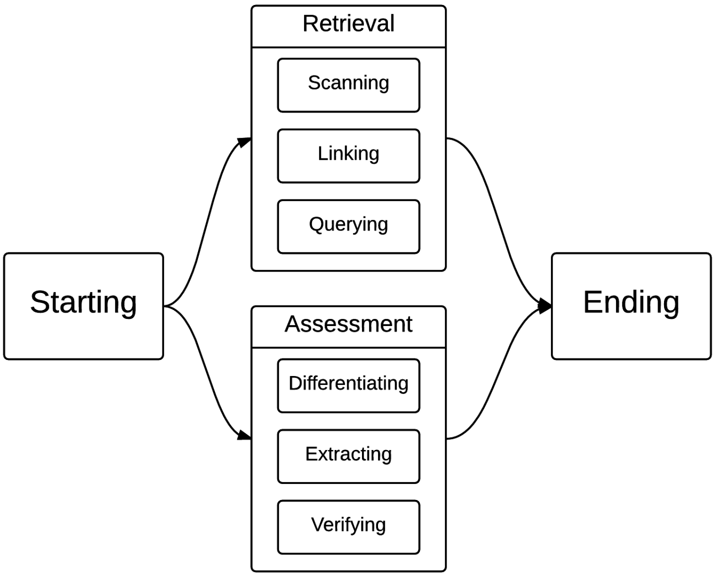

Figure 2.6: The activities of an information Seeking process. Retrieval and Assessment tactics can be composed freely.

2.4 Classification Techniques

In this Section, we will review in detail information classification techniques. Well-known techniques which originate from the pre-digital world (piling and filing) will be explained. Then, we will look at the possibilities of classification schemes in the digital domain (file system, tagging and faceted classification).

2.4.1 Filing and Piling

In a seminal study from 1983, Malone found out that the two most widely used classification techniques for the organisation of physical documents in physical environments are *filing* and *piling* [65]. The first means the ordered and labelled storage of information items by some kind of classification scheme. It can be best exemplified by filing cabinets. Therein, each information item is located in a named cabinet. items can ordered alphabetically, for instance. Actually, the idea of filing is well known for several thousand years. Aristotle already defined a tree taxonomy to decompose the world we experience [5]. Therein, objects can be derived from parent objects which are based again on other more high level objects. One important property is that there is only one unique path to each node, meaning every object can have only one parent. Whitaker [89] notes that users often started to create a filing system but soon abandoned it due to cognitive overload in the organisation and maintenance activity. On the other hand the search activity can be speed up by filing if the user is certain about her information need.

The logical ordering of *filing* is too rigid to represent complex and varying information structures. In general, information does not fit neatly into one categorisation structure. According to Lansdale this is due to ambiguity of natural language itself which is needed to describe this structure [62]. Also, the same information can be classified in many different ways depending on its context (task, topic, type, domain, complexity). Malone foreshadowed that the classification problem can be resolved by computer systems which allow multidimensional classification schemes [65].

On the other hand, *piling* refers to the unordered storage of information containers into clusters. These clusters are not like filing cabinets because they are not labelled and the items are located randomly, meaning there is no order. For Lansdale, *piling* is more a classification prevention strategy that compensates the inability to file a document unambiguously. It is less cognitively demanding and therefore more often used by knowledge workers. On other occasions, they remind the user that work needs to be done. Moreover, the proximity of piles on a desktop denotes the degree of importance. Malone and Barreau call this the *reminding function* which coexists besides the *finding function*. In general, piles are open in two ways. First, they deal with current working or warm information. To reflect, this they are always placed visibly in the workplace. Second, it is always possible to steer into the pile by grabbing randomly a sheet to look what it is about. Moreover, the user can always relate to piles in a spatial manner which helps to find information by recognition rather than recall. This is not the case for filed information. Normally, files are concerned with cold information and closed in a filing cabinet which is not open for direct visual inspection or reminding. On the other hand, piling does not scale really well for many documents whereas filing does. Another function of piles is the preservation of context. The way they are placed and grouped in space implicitly encodes meta information about a pile such as category membership or last access date, for instance. Also, Trullemans and Signer noted that files do not preserve this extra information well because it is often squeezed into labels [83]. Filing and piling strategies can be generalised into any other application domain.

Several studies found out that they are still relevant [58, 49]. But variations take place based on media and individual preferences or contexts. Users are different by age, gender, educational backgrounds, cognitive style, experience and many more [48]. According to Aykin and Aykin individual work style in digital environments is influenced by culture, personal style and other individual attributes [17]. For instance, older people might be reluctant to adapt new technologies to organise their documents whereas young people are more open to try out new technologies to organise their collections.

Also, users access information in different contexts. For example goals, nature of the task domain and complexity shape the work situation to a large extent. Also, the non availability of certain tools can have negative influence on the efficiency of a person. All these factors have tremendous effects on the way people organise their information. In the same realm, Kidd interviewed 12 knowledge workers [60]. They use information as the main means to produce value for the company. She points out that the interviewed persons relied less on filed information because they solve problems based on structures internal to them. They use the physical space as holding pattern for information, sketches and ideas which cannot be properly categorised. A specific spatial arrangement of documents can reconstruct a mindset needed for a task at hand. This also means that personal information collections are under a steady change. Depending on the context personal information is likely to be completely reorganised.

2.4.2 Digital File System

In the first place, modern computer systems such as databases or personal computers were heavily inspired by the filing strategy. The filing technique has been ported to the digital space via digital file systems where documents are titled and ordered within a folder. One major difference is that folders can also be encapsulated in other folders allowing an almost infinite depth and capacity. But digital file systems adopted the restriction from the physical space that a document can be placed only in one possible location. Therefore, the classification problem also holds here. The logical structure of digital file systems is depicted in Figure 2.7. Moreover, Dourish et al. identified three more shortcomings of digital file systems [40]. First, folders serve two conflicting roles. They are not only used to express a certain context or to group related files. They are also used to perform administration tasks such as backups or remote access which impose constraints on how to organise files. Second, files can only be retrieved in the same way as they were organised because there is only one unique path for each file. It is not clear why a file or a document can only exist in one unique location.

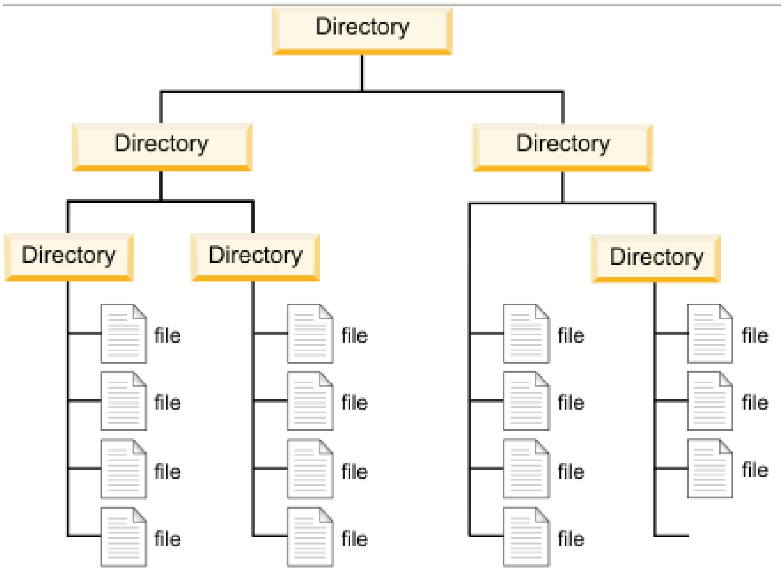

Figure 2.7: Logical structure of the digital file system consisting of directories and files.

In physical environments the user often relies on orienteering to seek for information. In digital environments, orientation is not given to us automatically. We must search for a visual metaphor to represent the underlying classification structure in order to obtain it.

In case of the hierarchical classification system the visual metaphor is quite straightforward. Its tree like structure can be easily represented by a wide range of visualisation techniques, ranging from traditional *tree diagrams* (depicted in Figure 2.7) to *treemaps*. Figure 2.8 shows the visualisation of the file system with the *treemap* technique. Navigation is often realised with the WIMP interaction style based on windows, icons, menu and pointers. It uses visual surrogates which are inspired by real folders and documents. Often, the top level of the filing strongly resembles a real desktop, it even shares its name. Here digital documents can be actually aligned spatially, even if only limited. For instance, items cannot be stacked to form piles like in the physical space. However, some kind of overview of the documents and folders can be achieved which can help to take further actions in the information seeking process. Navigation happens by following down or up the branches of its logical tree structure. Unfortunately, the user can cannot really preview the next level or even whole branches in the hierarchy from a certain location. The only hints are the labels of folders and files which cannot exploit the full range of contextual information existing in the physical space. Nonetheless, a sense of location is still given within the hierarchy of the filing system.

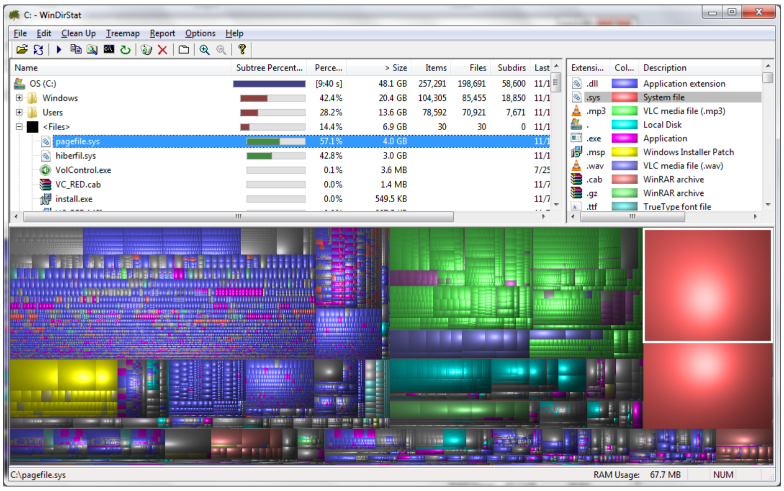

Figure 2.8: A typical organisation of files into a folder hierarchy visualised with the *treemap* technique. Taken from [7].

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2.4.3 Tagging

In the last 20 years the way people accessed, created and shared content online changed tremendously. With the advent of the Web 2.0 content creation and consumption is turned upside down. In the old Web, content was mainly created by big corporations and the user was limited to the role of the consumer. With social web platforms like Twitter[1], Facebook[2] or Blogs[3] the content creation is democratised. The user can now generate and share information without any economical or technical barriers. This big change also demanded a new way to organise the highly diverse output of information. One cannot apply a rigid hierarchical system to information which evolves continuously.

Unlike file systems, *tagging* does not impose any predefined categories. One can use any textual identifier to describe information. Moreover, an unlimited amount of these classifiers can be assigned to a single item. Imagine a book which is categorised with *Literature* and *American*. In the case of a digital file systems, this categorisation is only possible if one of them encompasses the other completely in a parent child relationship. But this is not

[1]https://twitter.com
[2]https://www.facebook.com
[3]https://www.wordpress.com

true here because *American* is not a strict subset of *Literature*. There are also other things imaginable which are *American* but not *Literature*. With tags, an object can be categorised as *Literature*, *American* or *Literature* $\bigcap$ *American*. All three ways are possible.

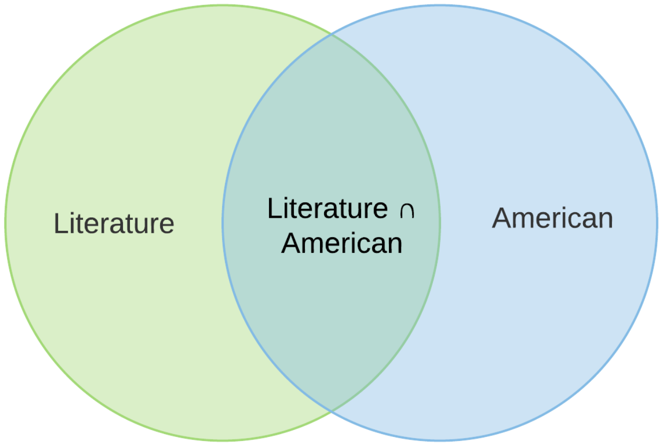

Figure 2.9: Example depiction to show the intersection of categories which can be modelled with tagging.

Moreover, tag systems reflect the vocabulary of the user and can incorporate new categories without any effort. Over time, categories undergo a change or disappear completely. For instance, the category *literature from the UDDSR* is obsolete now because it ceased to exist. As a replacement one has to come up with a new category which could be called *New Russian Literature*, for instance.

Almost any social web platform adopted tagging to some extent. Twitter uses them to categorise tweets which facilitates later retrieval or the creation of channels tackling certain topics. The same goes for Facebook which also offers the possibility to categorise comments, videos or photos with so called hash tags. Even user names can be used as tags to point the corresponding user to interesting items. Tagging is also used in a personal information context. Delicious[4], for instance, offers the functionality to save and categorise one's personal bookmarks. With Diigo[5] one can also organise notes, pdfs and pictures with tags.

All these services have in common that they use tagging for social interaction. Users share their tagged resources which aggregate into a community

[4]http://del.icio.us
[5]https://www.diigo.com

driven tag index, a so-called Folksonomy. This global network of shared content is used for exploration or recommendation of related tags based on user preferences.

But there are also serious problems associated with tagging. Users often apply similar but different keywords for the same content. For instance, the tags *visualisation* or *vis* mean basically the same thing. The only difference is that the latter is the abbreviation of the former. Often, users tend to forget throughout the process of organisation that they used a different tag for the same concept. Moreover, tags are context bound to a large extent. They only make sense to a single user and cannot be easily integrated into a Folksonomy.

Also, the structure introduced by tagged resources is much more complex than in file systems. Links between tags are defined by the co-occurrence of several tags on resources. Thereby, we basically obtain a graph which is undirected and can be cyclic. A graph is more difficult to traverse than a tree because there is no clear defined root node and there is normally more than one path to a certain location. It is easy to see that there is no clear defined navigation structure when one compares Figure 2.7 with Figure 2.10. It is not certain which is the optimal path from point A to point B.

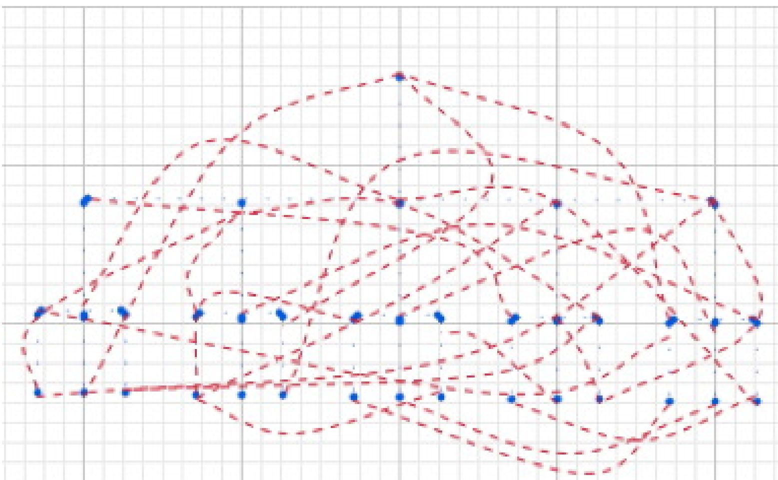

Figure 2.10: Graph structure to navigate in a tagged information space. Taken from [2].

This is the reason why tag spaces are often accessed with the alternation of keyword based searches and browsing result lists. Another widely used technique for navigation is the *tag cloud* which will be discussed in detail in Section 2.5.2.

2.4.4 Faceted Classification

Faceted classification combines the file system and tagging by embedding categories into hierarchical structures whereas each single category can belong to several structures. One particular example of a faceted classification scheme is the *OC2 framework* [82]. Its aim is to offer a unified view on personal information collections by relating information items from different sources with individual contexts and concepts by the user. Together, these elements form a three layered model which to some extent mimics the functionality of the episodic and semantic memory system.

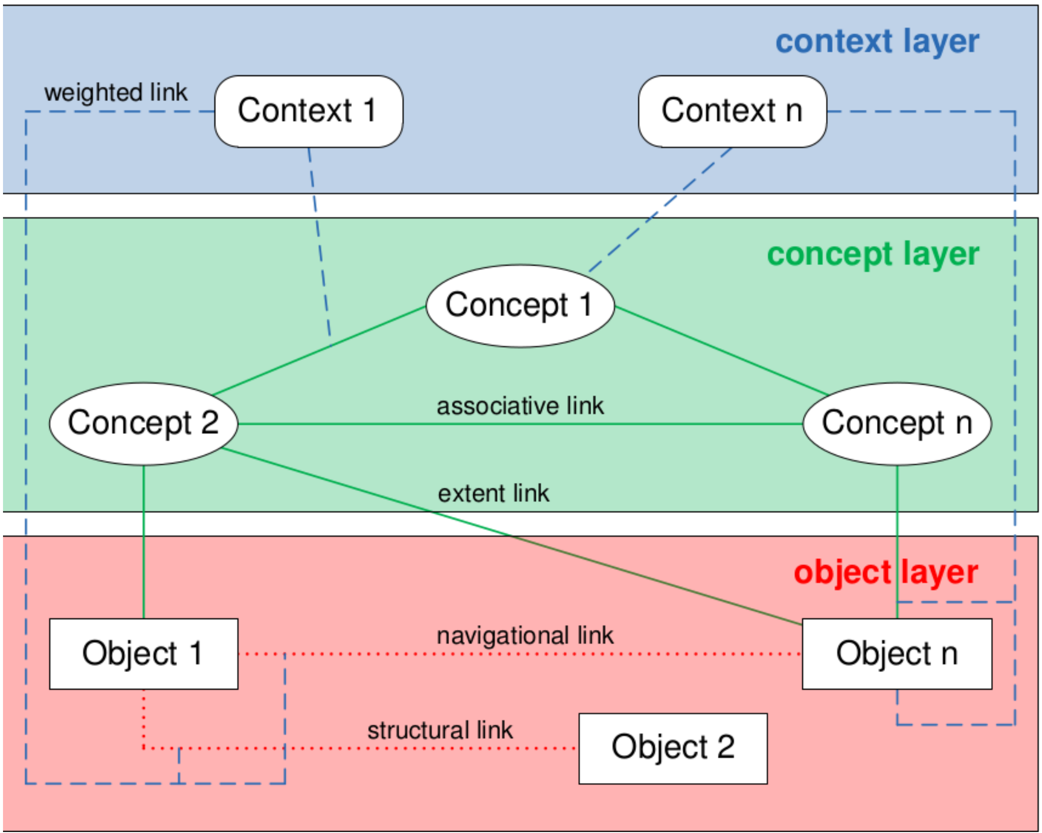

Figure 2.11: Conceptual schema of the OC2 Framework.

At the object level, the elements can represent any real world object such as paper documents, notes or emails. These objects can also be used to compose high level elements by relating them structurally. A book element can consist of several elements representing certain chapters. The concept level contains general ideas formed in the human mind to abstract complexity of the real world. For instance, a concept element representing a certain topic can be seen as a collection of books from the object level which are related via so-called *extent links* to the topic. Last but not least, the context level simulates basically the functionality of the episodic memory system by relating certain contextual factors to elements from the concept or object level. These factors represent situational attributes which can be important for the comprehension of concepts or objects.

In general, the problem of faceted classification systems lies in their inherent complexity. It is not far-fetched to say that building parallel hierarchies is cognitively difficult in practice. One cannot assume that users are always willing to invest time to create a consistent model of their information.

2.5 Information Visualisation

In this Section, we will establish the link between an exploratory information seeking behaviour and tagging. It was already highlighted that any digital classification system needs an interface to be navigated and searched. This requirement is not a natural consequence of the structure itself (unlike in the physical environment). Especially, in the case of tagging, a navigation structure is not obvious because it is not predefined. It is more a side product of organisation and can evolve in unexpected ways.

For this problem, visual exploration techniques can be beneficial because they seek to recreate certain affordances of the physical space when interacting with information. Especially, the notion of *orienteering* is important. It describes a sort of navigation where the user always has a sense of location within the overall information space [79]. This is especially helpful to carefully plan seeking strategies. In the following, we will review general guidelines and applications to support visual exploration before we will focus on techniques to visualise tags.

2.5.1 Visual Exploration

The idea behind *visual exploration* as defined by Dörk et al. is to gradually develop a sense of orientation with the help of visualisation in large information spaces [37]. It has been proven that the visualisation of abstract data can amplify human cognition to gain knowledge about the overall structure and internal relationships. Visual Exploration utilises these methods for query formulation and result presentation in contrast to traditional web searches which rely critically on text for querying and presentation.

For instance, with interactive visual elements such as time sliders, one can understand the effect of query adjustments better as shown in Figure 2.12.

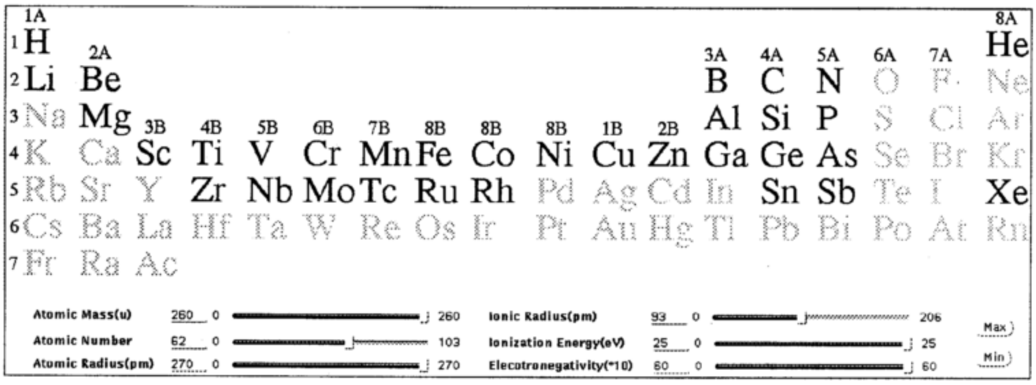

Figure 2.12: Dynamic Queries interface for the periodic table of elements. Taken from [13].

Search results can be visualised with the help of node-link diagrams which show topical sequences by connecting bigger topic nodes to smaller article nodes, for example. The so-called *spatialisation* techniques can be applied to implicitly encode key dimensions in space such that relationships become visible through distance (Figure 2.13). Navigation within these visualized spaces is achieved by offering individual filtering capabilities in the sense that each visual element can point to its neighbours which are defined in terms of similarity in their properties. With these techniques, *exploratory search* tries to satisfy higher information needs aimed at knowledge building rather than simple look up of information by creating an user experience which is at the same time engaging, high level, multi faceted and multi modal [36].

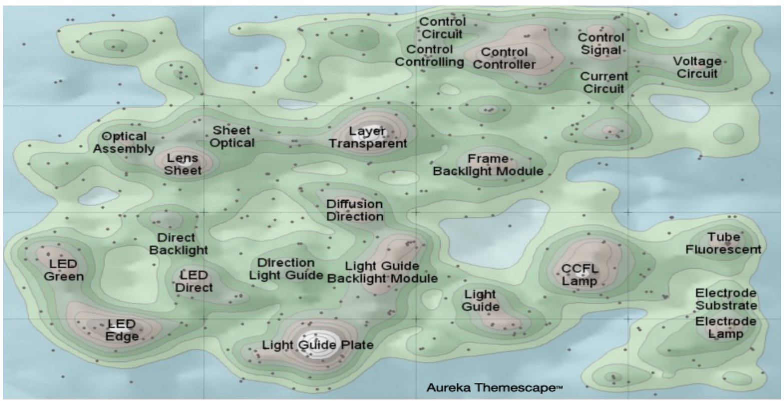

Figure 2.13: *Themescape* user interface highlights secondary data dimensions in a visual backdrop [91].

2.5.2 Tag Visualisation

In the following, popular techniques to visualise tagging will be discussed. The most famous candidate is the *tag cloud*. Basically, it is a collection of tags or words visually weighted by font size encoding the importance based on frequency of categories. Tag clouds perform extraordinary well in the starting phase of an information seeking process (as explained in Section 2.3.4) because they are striking visual statements and draw people's attention to important areas in the information space.

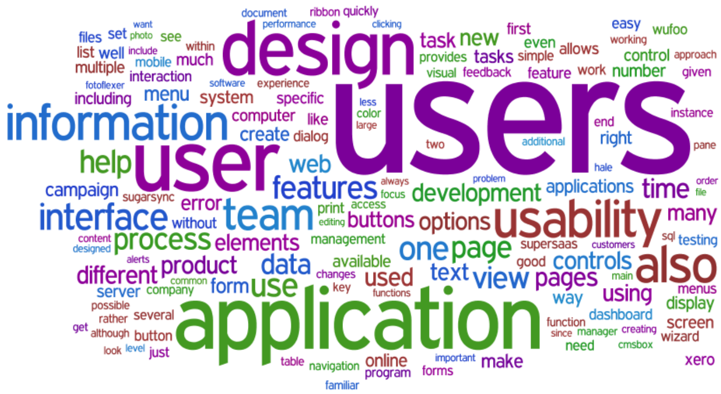

Figure 2.14: The tag cloud technique to visualize tagged information spaces.

They are often coupled with coordinated views which show the aggregated data in detail. Used alone, they cannot exploit every aspect of the information space because they ignore two other important attributes of tags. First, they cannot expose the similarity between different tags. Often, tags occur in company with other tags which denote a semantic relationship among them. Second, they are not capable to show the generality of tags. For example, *literature* is more general than *novel*.

One of the first candidates that incorporated relations into the tag cloud layout is the *parallel tag clouds* technique. It basically draws inspiration from *parallel coordinates* in the sense that aligns tags in columns representing different tag properties. Then links are drawn between tags to denote relationships. In [30], the authors applied this technique on large text corpora of court decision. Thereby, they could proof regional differences and linguistic differences between courts. Coupled with subordinated views Parallel tag clouds serve as a rich overview of large document collection and entry point to examine single documents in detail. Figure 2.15 shows the layout in action.

Word trees are also helpful to understand relationships in unstructured data. They do not only show the distribution of tags like tag clouds but they also reveal hierarchies of related words. This can be helpful to detect certain patterns in a text corpus. Another extension of the tag cloud is the *spark cloud* technique which is based on the idea to annotate tags with a micro visualisation technique called *spark lines*. With them one can easily discriminate trends among a set of tags.

The visualisation from [29] reveals visual web of keywords of subject headings to invite exploration of library collections which offered semantic links to similar topics. Another technique strengthened the navigational component of tag clouds is *WordWanderer* [35] which supports the gradual movement between related tags by integrating a comparison and a context view [35]. It was developed for analysis tasks in the context of corpus linguistics. One can easily spot co-occurrence of words or even select two words side by side to gain an overview other related words. [35] embedded a rich navigation facility into the tag cloud.

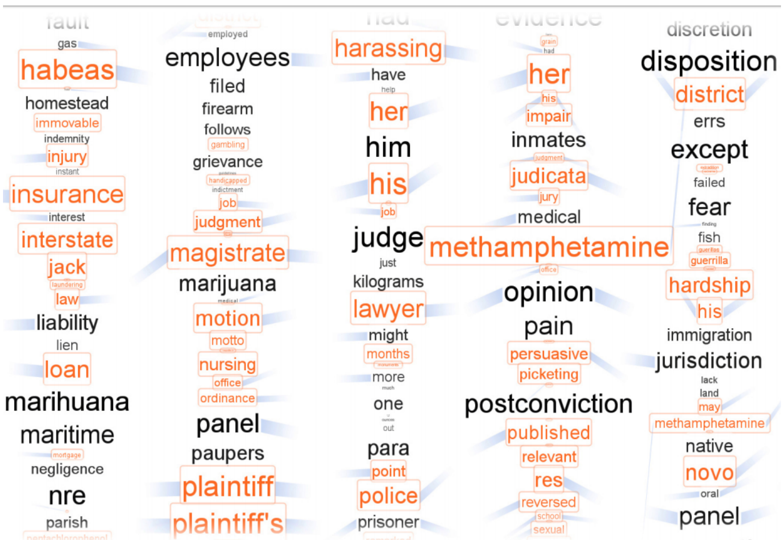

Figure 2.15: Visual Layout of *parallel tag clouds* showing the emergence of methamphetamine in court cases. Taken from [30].

3

Domain and User Analysis

In order to be able to design the exploratory search application TagVis with an user centred approach we need two more components. Firstly, we need a clear notion of the user and the domain where TagVis will be used. Secondly, A metric to evaluate the exploratory seeking behaviour is necessary. We have chosen to embed TagVis in the Personal Information Management (PIM) domain because it has not been targeted much by exploratory search application due to a misconception of the term as explained in 1.2. Many scholars argue that search behaviour in PIM is represented by refinding and hence essentially different [25] [56] because the first deals with unknown information and the latter with already experienced information. Others state that refinding is a special case of search but sometimes it can fall back to a more open ended way of seeking [57]. Searching of personal information is not either known-item search or open-ended exploration.

There is a hybrid approach which can make sense of refinding cues but is still based on uncertainty to some extent. The PIM community highlights the fact that refinding tends to involve more closed actions (refinding a telephone number). But what happens when the user is confronted with intellectual tasks such as interpretation, critical comparison and aggregation or integration of information? Then searching becomes automatically a more open ended activity. For the second component we identified user experience (UX) as suitable metric to measure the quality of exploration because they serve similar needs. Exploration wants to shed light on uncertainty of the user whereas a good UX stimulates and foster competence among others.

In a nutshell, this Chapter introduces the Personal Information Management Domain in detail and examine the role of exploration within it. Then, the concept of UX will be explained and its goals related to exploration. The last part of this Chapter will establish general requirements for TagVis which will function as the basis for the Design Chapter.

3.1 The Domain of Personal Information Management

The definition of Personal Information Management is twofold. Firstly, it covers the practices of collecting, storing, organising and accessing personal information by people in their everyday life. Secondly, the scientific domain of PIM is concerned with the study and analysis of these behaviour. From a user perspective, Jones categorises all possible behaviours into four distinct main activities which are keeping, organisation, refinding and maintaining [56]. Barreau also provided a similar taxonomy which examines PIM practices from an information systems view. For her a PIM system consists of components which aim to facilitate the integration and retrieval of information [18]. She identified three structural entities for any PIM system. First, there is the individual with information needs. Second, information carriers such as paper documents or digital files function as input for such a system. Last but not least, the activities of storing and retrieving information are also important. They serve the aim of knowledge construction.

It is crucial to know how the user interacts with a PIM system to exploit its quality. Often, PIM is initiated by the activity of keeping. A person has to decide whether they want to store an information item in their personal library. For example, the user encounters lots of information that is not useful at the moment but might be so in future. Unfortunately, it is difficult to foresee these future information needs. That is why many users fall into a so called *rat-pack* syndrome. They gather everything what they discover. In this context, the *MyLifeBits* project attempted to completely remove the keeping activity and instead applied a so called *save everything strategy* [45]. That means everything is kept by default. All user interactions are automatically recorded and saved in a personal lifetime store. It does not only store information items, also important life events are saved which can be useful to refind items in relation to them.

In general, the act of keeping enables the organisation activity which is concerned with naming, grouping, classification and placing information in a location for later retrieval. A typical challenge is the creation of categories to distinguish different collections [56]. The way how information is organised strongly affects the refinding behaviour. This activity refers to the set of methods users apply to return to previously experienced information. People use a wide range of contextual information to retrack information [83]. Last but not least, the act of maintenance is concerned with keeping personal collections intact in terms of updating the classification structure and the corresponding information items.

3.1.1 Tagging Personal Information

In Section 2.4, we explained the three most common classification schemes namely the file system, tagging and facets. The first is widely used for personal information but the shortcomings regarding a changing user context are too obvious. The second is the standard scheme for user-generated content in Web 2.0 applications. Its main drawback is the complete lack of hierarchy and the likelihood of having many synonymous categories. Faceted classification supports multi-classification but requires (like the file system) a predefined categorisation scheme. This requirement makes facets less flexible than tagging.

Recently, new interest in tagging emerged by the PIM community. Bergman et al. investigated the advantages of tagging in a PIM context. As already explained, it circumvents the classification problem elegantly by allowing multi- classification. Moreover, it is cognitively easy to perform because one can rely on the power of association to categorise content.

File systems are much more cognitively demanding when it comes to inserting new resources. One has to find the exact location for an item. This can be hard if the structure is deeply nested with specialised categories. On the other hand, with tagging, one can gradually improve accuracy of classification by adding more specified tags with time without having to worry about the organisation structure before an item actually arrives. Also, it is difficult to change the classification of an item once it has been inserted in the file system. It can be only achieved by moving it to a new location.

We can conclude that tagging is much more powerful for the organisation activity of personal information. The reason why it has not been adopted widely this domain lies in the problem of refinding. As already explained, people like to navigate and orientate in their personal collection. The inherent tree structure of file systems makes it easy to navigate to a location because there is only one unique path. As we have seen this is not the case for tagging.

3.1.2 Refinding

Unlike information seeking behaviour which involves unknown information targets to a large extent. Refinding functions on information which is already experienced. Therefore, refinding is regarded a much more target directed seeking behaviour because the user knows that the desired item exists and the only problem is the relocation. Besides knowledge about the content itself the user may hold a wide range of contextual information which describes situational attributes of an event bound to a specific information item [18].

For instance, a person still remembers how they found an old version of their favourite novel in the public library of their home town on a rainy day last spring. Research has shown that this type of contextual information provide important refinding cues. Barreau found out that people often refer to the physical location when trying to refind an information item. Trullemans and Signer also identified the time relative to the event as an equivalently important refinding cue [83].

However, it must be noted that knowledge workers often lose track of context due to high cognitive load induced by switching between tasks back and forth. This is especially prevalent in digital environments where contextual information is only poorly exposed to the user. They often squeeze these extra bits of information in folder labels which is only a sub optimal solution. Moreover, people are not always capable to unambiguously specify what they are looking for even in their own collections [33].

Uncertainty expressed in the information need has been rarely played a big role even when applied on large personal collections [41]. This is surprising because PIM search processes always happen in between these two extremes. Some personal domains are more characterised by uncertainty than others. On the one hand, there are rather simple administrative tasks which deal with rather simple information. And on the other hand there is the domain of knowledge work. Knowledge workers have to deal with a steady flow of new information that needs to be incorporated in already established classification schemes. This abundance of information can be hardly completely grasped in the moment of keeping. The file system rarely works out here. Many knowledge worker use piling to express a degree of uncertainty in organisation [62]. To refind an item the knowledge worker has to browse through these unordered piles directed by a clear information target.

This search process is exploratory to some extent, because the information is unordered and not completely grasped and also directed because the user has some spatial, contextual and temporal cues. With browsing, people gain an overview of the information space and also discover key landmarks in terms of information items which are special in some way [67]. Piling often results in a better understanding of information resources. This insight can be used to move resources from piles into a file system. Moreover, knowledge workers apply searches which involve several resources at the same time. For instance, topic comprehension or verifying a theory are not bound to one single information item. They are in line with learning and investigating searches as explained in Section 2.3.3. Thereby, the act of searching becomes the critical means to form new knowledge and to rethink established classification strategies.

It has been shown that people often apply a refinding technique called *orienteering* that enables them to slowly rebuild a particular context and therefore overcome uncertainty. Thereby, small situated steps towards a target are taken guided by other related items. These items function as landmarks to refine the information need. The behaviour of orienteering is based on a study by Teevan et al.. The authors examined how users refind documents across various electronic types (email, files, web) [79]. They further showed that orienteering circumvents the cognitive burden to exactly articulate what they are looking for. Users can rely on established habits throughout the navigation process. By applying small steps the user has a notion of location which gives a feeling of control and security in the sense that they are able to backtrack and change the search direction. Last but not least, orienteering gives contextual hints to the user which helps to better understand the results.

Orienteering often results in serendipitous rediscovery of information items. Some researchers regard serendipity as an unnerving and discomforting process [71] because expectations about a search result are not met in reality. Others argue, with serendipity, users can encounter information which might have been overlooked otherwise [58]. It can be argued that the effect is twofold. First, it can clarify or refine the information need in the sense that it can make the user aware of certain hidden information desires. Jones et al. highlight the relation to memory in the following way:

> *"The memory for how to access information is sometimes more 'in our movements', so to speak, as procedural knowledge rather than 'in our words' as declarative knowledge."* [58]

And second, serendipity confronts the user with a new perspective on the personal information space which can be beneficial because the user interconnects well known documents in new ways which in turn yield a better understanding of the investigated topics. Even when it fails, it can be of great value because it can uncover knowledge gaps. In many cases knowledge acquisition can be regarded as main motivation and outcome of refinding tasks. However, it must be said that searches which are focused on simple and specific information items do not often entail knowledge acquisition. When people searched for specific pieces of information such as phone numbers or addresses, then refinding is reduced to known-item search which is in line with the classic query-response paradigm explained earlier in chapter [79].

To conclude, refinding is often more than simply relocating information. It is a combination of exploring, understanding and reminding. What information one sees on the journey can be as important as the goal itself [75]. Therefore, it can be considered as an exploratory search technique to foster knowledge building. This aspect of refinding was rarely present in past PIM research. Often, the act of classification is only regarded to have a positive effect on the learning process of personal information [62].

3.1.3 Search Tools for PIM

In the following, we will review PIM tools which facilitate search tasks of personal information. To a large extent, they also make use of tagging as categorisation scheme. Already in the 1990s researchers questioned the predominant desktop metaphor developed by Xerox PARC. For instance, *lifestreams* uses a simple organisational metaphor, a time ordered stream of documents to visualise the diary of the user's digital life [44]. It replaces conventional files and directories by utilising software agents and stream filters.

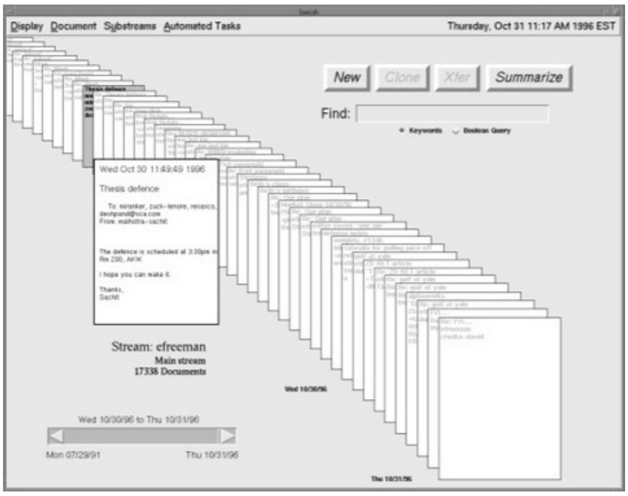

Figure 3.1: Lifestreams' visual metaphor for document organisation.

The system offers five basic operations namely *new, clone, transfer, find and summary.* The first three are concerned with creating, copying and moving documents within streams. With *find* the user can create substreams which provide a dynamic view on document subsets based on querying various metadata. In a sense, they are like virtual directories. Documents are not stored in the substream itself, they rather collect documents from other streams. When a referenced stream is updated then the substream is as well. Software agents come into play when the user makes use of the *summary* functionality which allow to distil information from various other documents into a single overview document. Unlike the traditional digital filing systems, Lifestreams does not reserve one fixed location for each document.

The *placeless documents* project called Presto stores documents by properties instead of locations [40]. Thereby, a property can be anything, ranging from static attribute such as a publication date, a user-defined classification such a task. Properties can be even derived by other properties with querying. For instance, the last access date at maximum two weeks before now is a typical derived property.

Properties are basically tags with one important difference. Not all can be assigned by the user. *Vista*, the user interface for Presto exploits this highly dynamic document model by using a combination of dynamic collections and multiple workspaces. When a collection is closed, it resembles a physical pile of paper. The other documents are represented by an oval like shape. The contour line also shows the dynamic query component of the collection. This functionality can be adjusted at any time to filter down big collections. All document collections are encapsulated in workspaces which can hold attribute objects to classify documents. They can contain different attributes and can be configured for different tasks.

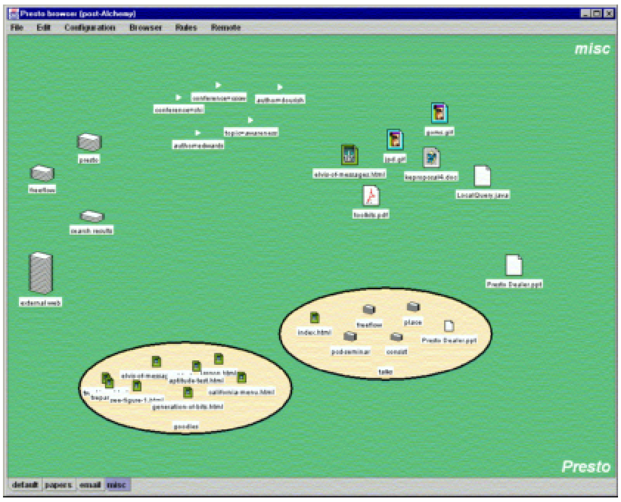

Figure 3.2: A workspace in Vista with opened and closed collections attribute objects at the top.

To some extent, Lifestreams and Presto lied down the foundations for multi-faceted classification of digital computer files. *FacetMap*, *FacetLens* and *ResultMaps* explored ways how digital documents embedded in multi-faceted structures can be navigated with ease [76, 63, 4]. They all used an adopted treemap algorithm to expose classification structures.

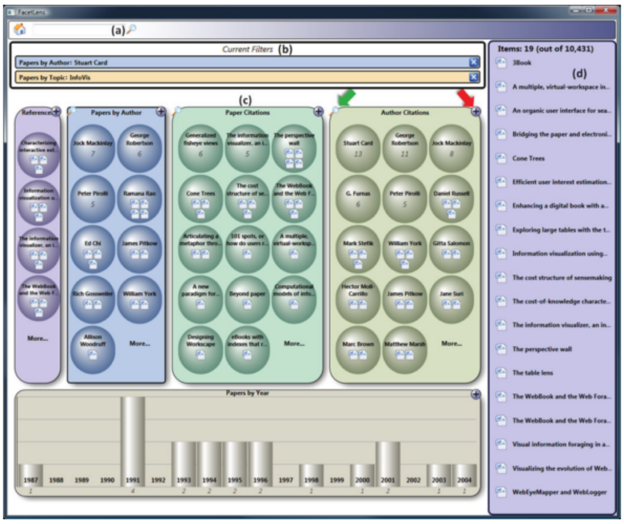

Figure 3.3: The FacetLens user interface shows several facets.

While the algorithm is capable of showing large document collections in a space efficient way, its overview capabilities are limited for large and nested hierarchies. Labels become unreadable when the screen size is shared among many encapsulated boxes. When coupled with navigation a sense of orientation can only be developed to the next deeper level and not in relation to the information space as a whole (much like in the traditional desktop metaphor). However, with the functionality to compose queries in a fully visual way, information needs can be much better translated than with keywords. The generic architecture of FacetMap and FacetLens makes it possible to a wide range of other data stores. It can be even adapted for tagged data.

Memory landmarks emphasise the importance of the time context. When people search for documents they often remember a rough time range when they have accessed the target document for the last time. They use relative time to narrow down the set of possible candidates. Memory landmarks enhances this strategy by applying a timeline based visualisation of search results anchored with important personal events (birthday, prominent news, events, etc.). Thereby, the user is enabled to associate her personal notion of time with the exact dates of document creation or access to facilitate search.

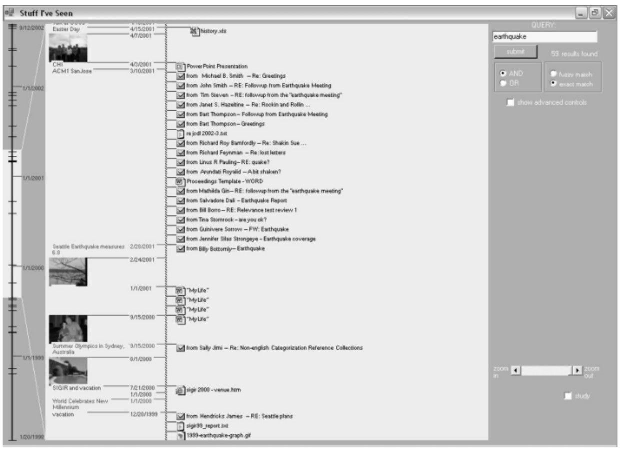

Figure 3.4: A timeline visualisation for the *Stuff I've Seen* project. On the left side one can see personal events which are related to search results.

3.1.4 Towards Visual Exploration of Personal Information

Building upon the notion of *visual exploration* (Section 2.5), we propose adjustments to this behaviour to be suitable for personal information. As explained in Section 3.1.2, people often refind personal information with three kinds of cues (spatial, temporal, contextual). Any visual search tool must expose these cues in the starting stage of the seeking process in form of visual overviews. They serve as the critical means to re-establish contextual factors for a certain event from the past. In other words, through certain key documents the user remembers some task such as writing an article or more open ended activities such as the comparison of certain topics. In turn, these concepts can spread activation to even other documents and it is possible that the process repeats itself.

With overviews the user can express a first direction in the seeking process to investigate in more detail. Thereby, the user can sequence and interleave several seeking tactics to form higher order seeking strategies as explained in Section 2.3.4. For instance, a person is cued by a temporal attribute of a particular document. To jump to some point of interest based on a topic, they can use querying. In the following, they scan through neighbouring documents (lying in the same time range) in order to gain a sense of location where they are in the moment. Finally, the person detects an interesting article which offers a pathway to leave the current topic for another one. Following up this chain, they find themselves in a new area of their personal collection. Now, they can choose whether they repeat the seeking process from before or they embark on a new strategy. Which tactic is applied when is not decided beforehand, it is decided within movements. Depending on what is discovered on the way other memory elements such as feelings, thoughts or interests are triggered which result in rapid adjustments of the current seeking strategy.

Notably, the visualisation in [39] is quite interesting because it perceives the information space as an arrangement of local individual perspectives (monads). Here, exploration takes place in the movement among overlapping monads. The layout manages multiple dynamic views to the information which makes it a perfect candidate for personal information management because people also hold a plethora of different but overlapping perspectives on their personal collections based on contexts.

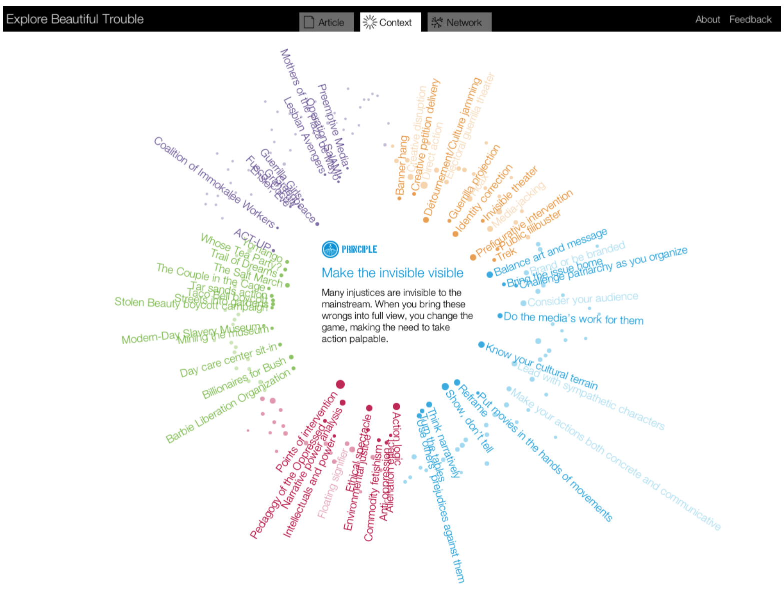

Figure 3.5: Monadic Exploration on references within a book. The proximity of concepts denotes relevance for a keyword search.

3.2 Exploration in Terms of User Experience

Exploration is a human experience and cannot be completely configured by a set of strict functional requirements. The user's emotions, expectations, goals and aesthetics play an important role to determine the overall User Experience [52]. In general, an experience is an event in time which is associated with sounds, feelings, thoughts, motives and actions. Highly subjective and context dependent no experience is like the other. For instance, kissing your future girlfriend for the first time can be hardly re-experienced. Stored in the episodic memory system, experiences can be re-accessed with the semantic memory system to reflect upon the event in retrospect [85]. In this process, the emotional tone of the event is enhanced or diminished. This active construction of an experience constitutes a narrative character. For instance, imagine a user of a computer game who successfully kills an end-boss after trying for hours. Within the action, the user is relieved and happy that they can finally move on to the next level. But shortly after they realise that playing for so long distracted them from daily work. In summary, the event is regarded as counter productive and negative. UX marks a shift from the product with its functionality, presentation and interaction to the users and their feelings. Focus is not any more something tangible and external. The transportation of dynamic and unique stories to the user is the focus of the design process. Software itself becomes the vehicle.

In contrast, usability is "only" concerned with the effective and efficient use of a system, product or service based on objective user goals. Emphasis is put on task performance rather than pleasure based on positive experiences. But usability is a necessary precondition for UX because without being able to learn a product and know how to use it no positive experiences can be transmitted. For Hassenzahl, the usability of a product corresponds to the perceived ability to achieve so-called *Do-Goals* (pragmatic quality) which represent functionality from a user perspective [52] [46]. These goals can be easily supported by products which meet usability standards. On the other hand, the hedonic quality is based on the achievement of Be-Goals which are decoupled from pure functionality. They origin from basic human needs which are centred on the realisation of the self and especially prevalent when interacting with products. In general, people strive to be effective and efficient in actions such that they feel competent for the whole activity. They also want to be free in the process to decide which actions are to undertake. But that is not enough, the ability to socialise i.e to communicate with others is also an important need. Last but not least, people also want to be positively stimulated by a product in terms of joy.

For the development of TagVis, the need to be competent, secure and stimulation are of special importance. People want to be efficient and effective in their tasks and they also want to feel pleasure when performing a task. The success of an information seeking process depends often on the user's discipline and motivation. When the information seeking process is unnerving and painful these two factors diminish rapidly. For instance, the presentation of search results in a plain list such as Google does cannot be regarded as a joyful experience. It demands a relative a high level of concentration. Over time, motivation can decrease because extensive browsing can be regarded as monotonous. A search interface which represents results in a more visual pleasant way instead of applying a boring list of items such as Google can immerse the user much better in the search activity. Figure 3.6 shows the interface of *Oskope* which aligns search results on axes to represent different characteristics of them.

Figure 3.6: Oskope allows to align search results on axes to represent different properties.

3.3 Introducing Personas

In order to design for experiences instead of things, Hassenzahl proposes a simple conceptual model based on three dimensions how to view the product embedded in the world [51]. The starting point for the design process is always the user's motive i.e. what does the user want to represent with using the product. The designer tries to comprehend these Be-Goals in order to be able envision the overall experience and to foresee the functionality. Only then, this experience is translated into a design which takes into account the context of usage [77].

This model perfectly aligns with the structure of *personas* which represent the target audience of a product, software or service. They summarise large amounts of data derived from interviews, observations or experiments into a user characterisation. The resulting goals, motivations and context are depicted in a story that also takes into account subtle distinctions among other user types in terms of interests, aptitudes, preferences and dislikes. This high level of detail is important when one wants to design for deeper psychological needs that establish positive experiences.

Much like the model of Hassenzahl, personas structure information around three dimensions namely *what, how and why* [31]. The first is concerned with the Do-Goals the user wants to achieve with the product. In the *how* dimension strategies are derived to solve these goals. This encompasses the tools used to facilitate the task, environmental factors such as how the office is set-up or even ergonomic problems which complicate the task such as uncomfortable sitting position. The How dimension is important to understand the user's mental model i.e. the beliefs formed around the way the user approaches the task.

The *why* dimension sheds light on intrinsic needs which are roughly in line with the Be-Goals explained before. It clarifies the psychological needs which are involved in a problem solving process and the resulting emotions. What does it mean for the user to use the product? What emotions are invoked when the task or problem is accomplished?

During the development process personas can serve multiple purposes. First of all, it can be used to explain the target users to a wide range of stakeholders (developer, clients, analysts) in order to derive a set of functional requirements. Furthermore, it can be used as a design tool. For instance, they can aid designers to internalise the user's mental model. Also, they typically appear in storyboards and scenarios to guide the process of sketching and prototyping [68].

3.4 The User Model

In this Section we will materialise three types of information seeking with personas. They will serve as the basis to derive a set of requirements. But before that we will gather some common problems users have with traditional search tools.

As already mentioned before (Section 2.3), the query-response paradigm is the predominant mechanism how people find information. It is based on the alternation of two distinct practices. First, a search query must be constructed to yield results. Then, these results are reviewed and the query is refined when the information need is not satisfied. It is not only used in the context of the Web. Also, on personal computers and smartphones it is the default way to find information. We already elaborated on the shortcomings of the query-response paradigm earlier. Now, we leave the ivory tower of academics and step into the dirt of social media to examine what users think about this way of searching and what they are missing. One interesting blog entry quotes that Google is handling known item and open ended topic queries differently. For instance, the query *vietnam weather* will yield the expected result, whereas *vietnam travel* will produce a wide range of different results [6]. The comments point out that the query-response paradigm is minimal but it performs quite well when performed sequentially in order to track down a particular item. In a Reddit[1] post, users complained about the monotony of the result browsing experience. Especially, the frequent switching between the result pages is criticised as annoying and blurring the focus [12].

In general, users are unsure how to formulate a query for Google to obtain the best possible search result. Also, it seems that people sometimes do not understand why a particular result is considered relevant. This highlights a deeper problem of the query-response paradigm. It is rarely transparent. An algorithm tries to match the query to a nearly perfect item. When it succeeds the result is represented in magic like fashion. The user is directly teleported to the result without making her understand why exactly this particular item resolves their information need. In general, the web community makes the impression that it is difficult to look beyond the horizon for alternative search tools. Most users do not have knowledge of the extensive research performed in this field as shown in Section 2.3.3. Online discussions rarely explicitly highlight deeper problems of the query-response paradigm.

3.4.1 Eli, the Chaotic Explorer

Eli is the first Persona. He is a somewhat unorthodox scholar and thinker. On the one hand he is heavily engaged in research work in preparation for his doctoral thesis but on the other hand his approach to research deviates heavily from well-established working practices. He cannot stand rigid classification schemes. He does not spend much time to organise his documents when he encounters them for the first time. He relies on spontaneous associations. Whatever keywords come to his mind at the moment of keeping serve as primary classifiers for the document. Even though he hardly grasps the document's scope. As a consequence, the used categories are not always

[1] https://www.reddit.com/

accurate. But due to the fact that he always uses more than one keyword he can easily recreate a certain mindset for a task. In technical terms, he uses tagging as primary technique as explained in Section 2.4. Currently, he accesses his digital collection with a web tool which offers a tag cloud and lists as main technique to navigate documents.

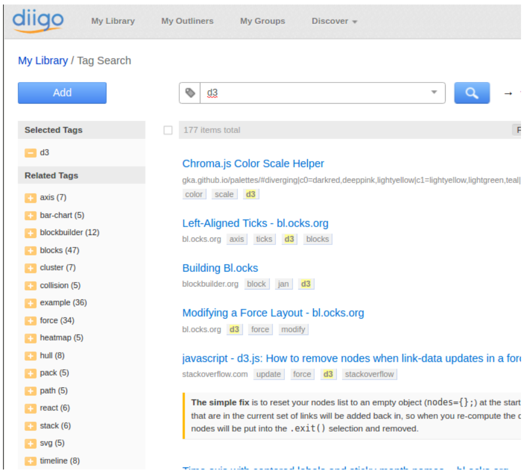

Figure 3.7: Diigo[2], the web tool used by Eli to exploit his personal document collection.

He thinks that result lists are useful in terms of effectiveness and efficiency but unsatisfying because he is never surprised by the outcome of the seeking process. In general, he likes to discover things, not only in form of documents but in also in terms of establishing some hidden relationships among documents. That does not mean that he wants to have some kind of automatic recommending system which tries to analyse his habits and present an interesting result in a magic like fashion. He wants to able to follow trails of associations he makes with content in an unconstrained way. The tool should be invisible and not interfere in his endeavour to build knowledge.

Scenario

We define an ideal typical task for Eli which captures his specific needs in a process of actions. Eli is about to prepare himself for a presentation tackling the topic *conception of art and science in the romanticism.* In this context, expresses the following search problem: *"I want to refind this one paper where the author rephrased a famous theory by Einstein and then criticised Newton."* First of all, the author is not known nor the name of the theory. The only known fact is that there is a semantic connection between Einstein and Newton in one of his documents. As one can see, the search problem can be attacked with several different strategies. For instance, one could scan for papers which reference Einstein or try to reread the original Einstein or Newton to come up with better keywords for search. In any case, the the search problem is ill-defined because of many unknown variables. Eli decides to enter the seeking process by applying a keyword search on the term *Einstein* to teleport roughly into the area of interest in his information space. Then, he makes use of the browsing strategy to get an overview of the possible relevant material. He discovers that there is one resource tagged with *Einstein* and *Newton*. He expects it in detail but concludes that it is not the right one. Therefore, he chains this document to another document via a subset of common tags. He repeats this process several times before finding the right document.

3.4.2 Gerd, the Hobby Librarian

Gerd is to some extent the antithesis of Eli. He is professor of humanities and can look back on a long history of research with several articles and some books. In his personal library, he holds all relevant resources to perform research. Currently, he is working on a literature review of American modernist novels from the 20^{th} century. Like in all of his projects, he makes extensive use of primary and secondary usages.

He is a strong advocate of hierarchies. He maintains a big organisation taxonomy which covers all his documents ranging from private to work related. The structure is flexible and rigid at the same time. It allows the creation of new categories. But the sheer quantity of categories demands that every new document is reviewed in detail to decide whether it can be placed in one place. This is not a problem for Gerd because he inserts documents at a smaller pace than Eli. For retrieval, he spends a fair amount of time to specify the categories of interest. The results are reviewed with the same patience. Depending on his satisfaction he readjusts the initial query to refine search results. His documents are almost completely digitised. He is used to interface his collection with long textual lists and is not fond of graphical bells and whistles that augment the User Experience. Nonetheless, he is aware that he gets lost in its own structure due to its complexity.

Scenario

The scenario for Gerd is defined as follows. Recently, Gerd travelled to New York City and visited a private library to search for early correspondences between F. Scott Fitzgerald and his wife Zelda in order track down autobiographic analogies in his novels. He found a pile of 30 letters. Many references to biographical events are unknown for Gerd. Some other letters might already be in his archive. Back home, he is confronted with two types information needs. First, the fact that some of his brought back letters are already in his collection needs to be verified. This problem can be easily solved by a known-item search. In contrast, some passages in the life of the author are still unknown. Therefore, he cannot relate some letters to events in the authors life. These knowledge gaps require a search which encompasses a wider scope in order to minimise his uncertainty. He makes use of browsing to get an overview of all official biographies of the author. He reviews them carefully to shed light on important events depicted in the letters.

3.4.3 Lisa, the Reluctant Computer User

Lisa can be described as a typical casual user. She uses her personal collection mainly for emails and notes to organise daily activities such as meeting friends and some other administrative tasks. To a limited extent, she also holds documents relevant for her studies in form of articles, books and notes. But she is not obsessed with their organisation or the exploration of documents. On her computer, she keeps a few folders whose labels represent high-level contexts such as *private*, *friends* or *studies*. She uses seldom a sub classification resulting in the fact that she does not perform many exploratory searches in form of recalling a category that describes the content of a document. Instead, she often tries to remember the file name or the point in time of document creation. When she still cannot find her desired documents, she applies a browsing strategy through her folders. All in all, she is not fond of technology, she only uses it to the extent that she can resolve her daily information problems.

Scenario

A typical problem resolving process is defined in the following. Currently, she is engaged in organising a birthday party for her best friend. This involves the creation and sending out of invitation cards to friends. Moreover, she employed a catering service to provide the food for the party. The information for the invitation cards can be easily retrieved from her contact list with a known item search. But to find a qualitative catering service which is not expensive she needs to compare several offers. Therefore, she scans all companies which are not located too far. She also needs to consider the preferences and dislikes of the guests when she chooses the menu. This is a non trivial problem because the guest list exceeds 20 persons. To make a good decision, she needs to be in the best possible state of knowledge. Therefore, she collects all personal information regarding food from personal emails with them.

3.5 Domain Constraints

In the real world, any user centred development process has to face a set of constraints which are not directly related to the end user needs. Often, they origin from environmental, technical and business rules expressed by the customer of the software product. In context of the development of TagVis, we have to deal mainly with technical restrictions due to the inherent complexity of classification structures. As already highlighted, tagging is widely used in Web 2.0 applications. Unfortunately, the used data model of the corresponding information items differs slightly.

To strengthen the practical relevance and the flexibility (regarding different data formats) of TagVis, a minimal data model will be assumed. Category tagged documents with time stamps and optional author field will serve as the main structure.

3.6 General Requirements

To summarise this chapter we will synthesise the three personas discussed before with a set of Do- and Be- Goals according to the classification by Hassenzahl [51]. Thereafter, we recapitulate shortly the technical constraints. The following Do-Goals give a high level account of the functionality provided by the tool.

1. The user shall be able to perform visual exploration as described in Section 2.5. This entails the ability to browse through personal documents guided by semantic relations. Two documents are semantically linked if they overlap in some subjects they tackle.

2. Search based on meta-attributes shall be supported. Meta-attributes encompass information such as authorship and date of creation. They can be used as cues to retrieve documents.

3. To support the case that the user is completely certain about her information needs, directed keyword search shall be supported to jump directly to the desired document.

4. Requirement 1 and 2 shall be easily combined with each other such that the user can easily apply hybrid information types of information seeking which reside between the two extremes of exploratory search and target oriented keyword search.

The Be-Goals focus around competence and stimulation.

1. First of all, the user should be empowered to exploit knowledge from their personal document collection. A deeper understanding of the documents shall come into effect automatically by using the application. Negatively spoken, the application shall show knowledge gaps to the user by explicitly marking areas of interests in the information space which are weakly covered by documents.

2. The ability to immerse into the search activity shall be fostered through visualization techniques. the creation of mental maps for topics shall be facilitated. Moreover, the user shall have fun when they are searching for something.

4
Design

The requirements are set. Now, it is on the time to develop a functional design for TagVis. It assumes tagging as underlying classification scheme. We make use of the user centred iterative design approach in the sense that we will create design sketches and evaluate them against the personas developed earlier to foresee possible problems.

The agenda of this Chapter can be read threefold. First, a methodology needs to be defined in terms of distinct phases for the development process. Second, a general overview of suitable techniques to visualise tagging needs to be established. And finally, the design methodology needs to be executed.

4.1 Methodology

The design method is based on phases and iterations. In the first phase, the scope of possible solutions is envisioned. Then, several throwaway prototypes are developed each targeting a different problem vector and the quality of each prototype is measured against sample data. The focus is put on the quality of visual representation in terms of the overall readability and the ability to reveal the semantics of the underlying data. Typical questions to be addressed are the following. *Do visual patterns reveal the semantics of the underlying data? Can the user easily overview the personal information space by identifying points of interest?*

This phase is not concerned with typical usability metrics such as task effectiveness, efficiency or the time to learn the system. They will be assessed later (Section 4.7). When a prototype for the core visualisation of TagVis has been chosen, a new phase starts. Here, emphasis is put on the other Do-Goals. We will assess how the core view of TagVis can be extended with subordinate views to tackle meta attributes and directed keyword search. When they pass this test the integration phase becomes active. Here, we integrate the core and sub views into a working system. The final phase is the evaluation. We will test the usability and the overall User Experience. Figure 4.1 summarises this methodology.

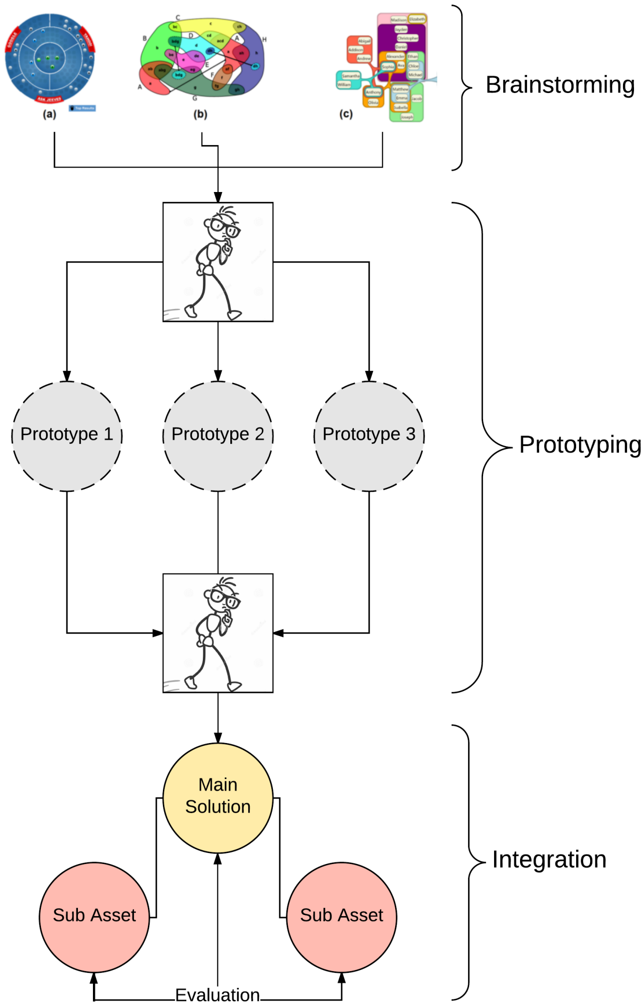

Figure 4.1: The different phases of the applied design methodology.

4.2 Phase 1: Brainstorming

In this phase, we obtain a clear understanding of the challenge to visualise tags. In general, the problem to visualise tagged documents and their relationships can be reduced to the problem of visualising set memberships. Every document exhibit a set of categories and every such set has intersections with other documents. Luckily, the authors of [16] already performed an extensive literature overview tackling this problem. The techniques presented are ranging from traditional Venn diagrams over graph representations to bubble sets.

For Alsallakh et al., the Achilles heel of set visualisations is the issue of scaling. Almost all techniques perform quite well for a low number of sets. Unfortunately, it has been shown that n sets have 2^n possible intersections. The visualisation of many sets is a hard challenge and in the case of Venn diagrams visual clutter is inevitable. Especially, in the case of tagging the ability to multi-classify, naturally comes with many overlapping categories. Moreover, users tend to apply a wide range of different tags of which some describe similar concepts. The visualisation research community makes a big afford in making set visualisation more scalable. The authors of [16] identified three family of approaches. Overlay techniques build upon the basic metaphor of Venn diagrams having geometrical forms overlapping to denote intersections. A famous candidate is the *bubble set* technique which makes use of the *marching squares* algorithm to create contour lines around a set of points. Line Sets and Kelp Fusion further improved this approach by minimising space usage [70, 15].

Node-link Diagram techniques represent set memberships as edges between nodes in a graph. Sets can be modelled as explicit nodes and links to other nodes denote a subset relation. Finally, aggregation techniques depict only the sets on their own and not the individual elements. A wide range of visualisation techniques can be used in this context. The techniques described in Section 2.5.2 fall into this category.

4.3 Phase 2: Prototyping

In this phase the core view of TagVis will be designed. We will examine how the similarity and the relationships between tags can be expressed optimally. We develop three prototypes each targeting different aspects of tagged information. Each will be reviewed according their value for Visual Exploration.

4.3.1 Prototype 1: Venn-Node diagram

According to the brainstorming phase, *Venn* diagrams are not really suitable for large amounts of sets. Nonetheless, we started with this approach for two reasons. First, we wanted to see what is the maximum number of sets which can be visualised with this method (when does it break exactly?). Secondly, it was considered to use Venn diagrams to present sub parts of the overall information space. Figure 4.2 shows that the method already lacks readability for seven sets.

Another concern is space consumption. Plotting many circles takes much screen space and therefore cannot be scaled properly for wide screens. Therefore, we started all over and applied a *node-link* approach which uses links to denote set memberships instead of surrounding circles. The strategy is two fold. First, a graph layout with sets as nodes is initialised. Second, all set elements e.g document surrogates are pushed to the corresponding positions.

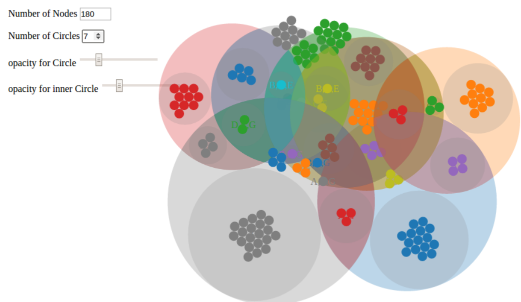

Figure 4.2: Venn diagram for seven sets and 180 elements with lack of readability. Adapted from [8].

Figure 4.3 exemplifies this approach. Unfortunately, the readability is even worse than in Figure 4.2. Disappointed by this result, we concluded that it is impossible to show all sets and their intersections explicitly. Their presentation needs to be aggregated to some extent in order preserve readability. This insight will shape the design of the following prototypes.

4.3.2 Prototype 2: Facet Viewer

Puzzled by the outcome of the first prototype, we decided to decouple the positioning of sets and their elements. Here, not only sets are included, also the time attribute is considered. Figure 4.4 shows the prototype. It partitions the visualisation into three layers. In the middle, one finds all documents aligned as a pile. This layer supports a natural browsing experience because when a single document is hovered all neighbours are pushed away to support reviewing of the focused document. In the upper layer, tags are visualised in a tag cloud manner, meaning the names are plotted as text and their size encodes the frequency used to categorise documents (tag-document relationships are represented with visual links). The lower layer showing the timeline works in similar fashion. Here, dots are aligned on an axis representing the time range in which all documents have been created.

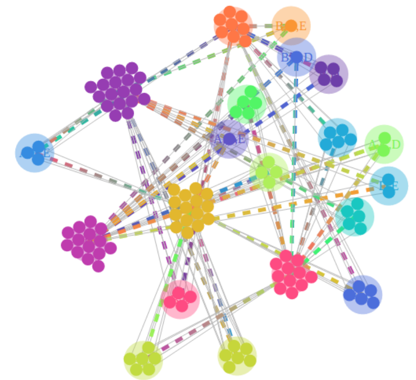

Figure 4.3: Node-link layout for 5 sets and 120 elements adapted from [8].

All three layers are connected with links between their elements to highlight different attributes of the source documents. This idea was inspired by the layout of the *OC2* framework (Section 2.5). Much like OC2, this prototype structures semantic and contextual time information around the information elements which are aligned in the centre. In general, this technique can be used to show additional dimensions of the underlying documents because the canvas can easily be partitioned into more segments. Each of them could show another dimension of the data. With interaction facilities, one could define complex visual queries by selecting elements of the different layers which in turn would change the data visualised by them. Unfortunately, the visual clutter introduced by the links between the elements would be even worse with more layers.

Hierarchical edge bundling [54] could be used to group visually several links having the same target node. This prototype was not developed in more detail because it uses a *force spring* layout to cluster nodes according their dimension (document, tag, point in time). Hence, it relies on several constraints for positioning, also for collision detection. Naturally, they conflict each other and the layout algorithm has to find a state of balance for all nodes. Unfortunately, constraints are not really supported by the used *force layout* in D3 3.5 [22].

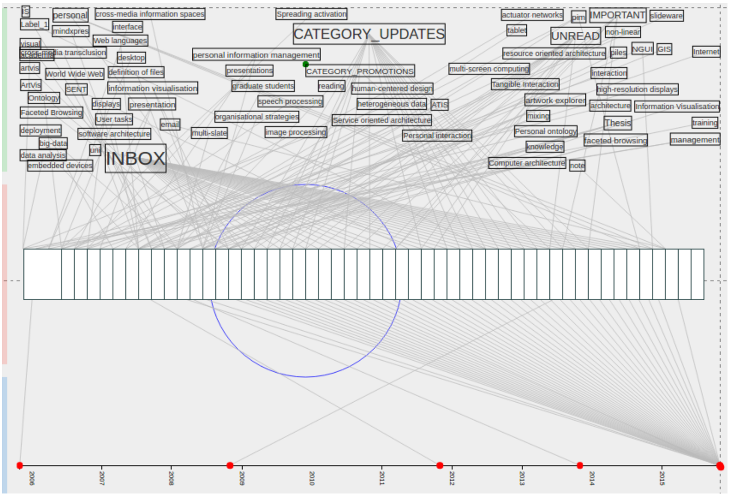

Figure 4.4: Partitioning the canvas into three layers. Each of them depicts another dimension of the data. In the top, one can find the used tags. In the middle, the documents are shown and in the lower part the creation time is depicted.

4.3.3 Prototype 3: Bubble Node Diagram

The third prototype started with the idea to use the node-link diagram technique developed for the first prototype but to replace the links (which denote intersections) with a technique that scales better. The visual clutter was mainly produced due to link overlaps in Figure 4.3. We decided to use the *bubble set* technique because it is location agnostic. It overlays any set of points with polygons denoting intersections. Readability is much better than in the link based approach because overlapping polygons create less visual clutter. But also this technique reaches its limits when applied on 10 or more sets.

4.4 Conclusion

As expected, scaling was the biggest problem of all three attempts. This phase was started with the really limited technique of Venn diagrams. Second, we developed the node-link approach which did not perform any better. And thirdly, we addressed the question namely how different views can be coordinated by partitioning the whole application into three layers. Finally, we applied the Bubble Set technique as a replacement for the links in prototype 2 to have better readability. In the next phase, we will set the foundation of TagVis by joining the three prototypes into a visualisation technique which is capable of presenting a large number of intersecting sets. It will form the core view of TagVis.

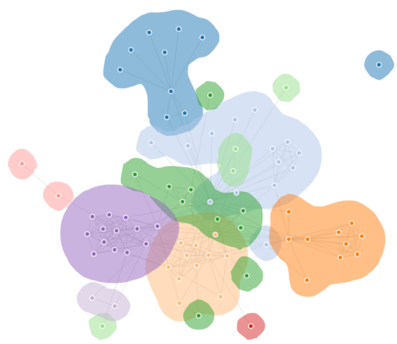

Figure 4.5: Bubble set technique used on a node-link diagram consisting of 8 sets and 76 elements. Adapted from [1].

4.5 Phase 3: Integration

This phase marks a big mile stone in the development process because we integrate all the benefits of the three prototypes into one solution which performs well for a large number of sets (Core View defined in Section4.1). Also, two views will be developed which are responsible for the subordinated requirements of directed keyword and meta attribute search defined in Section 3.6.

4.5.1 Core View: ClusterVis

First of all, the visualisation technique introduced here will serve as the main navigation facility for TagVis. It will foster the visual exploration behaviour from section 2.5.1. But it is also novel from a pure information visualisation perspective because it aggregates groups of data without lacking detail and present them with a hybrid approach combining overlay and node-link techniques.

It uses an improved graph structure developed in section 4.3.2. The derivation of this structure will be the main subject of section 5. For now, it is only important to know that it reduces the overall graph structure into disconnected hierarchies which is needed for the application of bubble sets. The bubble set technique is applied locally on a group of tags which occur often together as can be seen in Figure 4.6.

Figure 4.6: An aggregate cluster showing a connected component of documents which are tagged with *pim*, *orienteering* and *organisation*. Hovering one of the bubble sets highlights the exact tag which used as category.

The selection of these aggregate groups is achieved with the *tag graph* structure explained later (Chapter 5). A bubble denoting a subset of a particular group can be hovered to expose the tags used for the categorisation of corresponding documents. Actually, each group represents a connected component of the underlying tag graph. The size of a group is measured by the maximal path length of the underlying connected component. Sometimes, these components can be really large and inhibit too many sub sets. Then, The bubble set technique produces too many overlapping bubbles in a certain location. This results in poor readability for the whole visualization. Therefore, we defined a threshold value which can be adapted for differently structured tag spaces. When the threshold value exceeds for a connected component the corresponding group is cut in two and not bound to same location any more. To denote that two groups actually originate from the same connected component we connected the corresponding groups with visual links. The links serve as facility to navigate throughout the information space. The user can select the links to jump to a neighbouring group. This form of navigation is an important requirement for an exploratory seeking behaviour. Figure 4.7 shows the overview of a personal tag space with several aggregate groups and their connections.

For instance, the aggregate group labelled *joy-division, pop, visualisation* has a connection to the group of *visualisation, animation, design* because they share the tag *visualisation*. Moreover, the link opacity and thickness denote how strong the connection between these two groups is. One must note that transitive links are not included. Otherwise, the number of links would introduce too much clutter. To make that relationship more evident, one can select the tag labels of aggregate groups to see occurrence of this tag in neighbouring groups (right part of Figure 4.7).

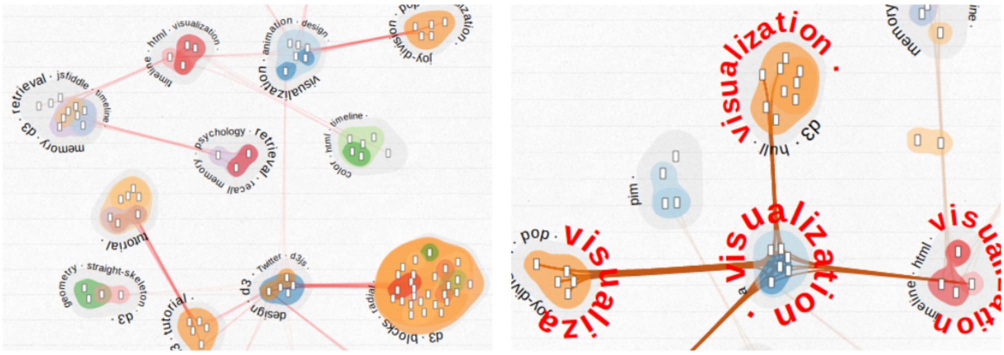

Figure 4.7: On the left side, one can see a collection of aggregate groups and their connections. The right side depicts three aggregate groups which are connected via the tag *visualisation*.

Moreover, they function as navigational links to move between related groups i.e. they share documents with the same tag. Thereby, we have implemented the orienteering requirement of visual exploration (Section 2.5.1). The user has a sense of location and can move in horizontally through the information space. Also, vertical movements are supported by a zoomable user interface. First of all, one can zoom in single cluster to review their tag memberships in more detail. Also, one can preview documents by zooming into them directly.

With this technique, one can visualise large personal information spaces by keeping visual clutter at a bare minimum. Furthermore, it will be coupled with two subviews which enable the user to move more target-oriented in specific areas of the information space.

4.5.2 Sub View 1: TimeCloud

Currently, the time variable of personal information is not yet supported. It is needed to achieve the *search by meta attribute* requirement from section 3.6. The general idea is to aggregate user tags to categorise information according to the time when they were created. To support exploratory search behaviour, the gradual refinement of the time range should be possible. We achieve this by combining the tag cloud technique with a time line approach. In concrete, particular tags are positioned on an axis corresponding the date of creation.

Figure 4.8: Tags used to organise persona information aggregated to their year of creation.

In Figure 4.8, one can see that tags aggregated by the year. In this case, all documents are created in 2016. When one applies a zoom interaction tags are aggregated to the next finer level, which is month (depicted by Figure 4.9). This step can be performed again to scale down the aggregation level to days. Thereafter, the user can stretch a particular time interval to express a focus. For instance, if one is only interested in the tags used in the first two weeks of a particular month one can apply a zoom interaction in this area to translate the underlying scale of the axis such that emphasises this interval of time. This view will be coupled to the core view to filter down the selection visualised by it.

Figure 4.9: Tags aggregated to the month of creation.

4.5.3 Sub View 2: SearchTree

This view is created to satisfy the directed search requirement from Section 3.6. It enables the user to explore related tags. In the beginning, the user is confronted with a bare list of tags. Again, the font size depicts the occurrence used to categorise documents. Either, the user can browse through that list or filter it down with the search facility. By clicking on a tag the list is updated and indents all related tag elements. When clicking again on such an element the list expands again and shows all tags which appear together with the first two tags. In fact, this dynamic list is based on a tree structure and is changed dynamically when the user decides to review a certain branch. Furthermore, it is coupled with a directed search facility to select all the tags which contain a certain string of text. Visually, it draws inspiration from the Tag Cloud technique explained earlier 2.5.2. But related tags are aligned vertically instead of horizontally to save space in combination with scrolling.

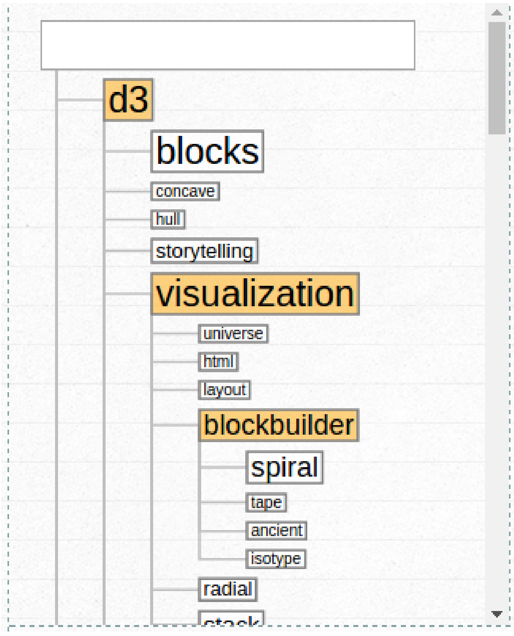

Figure 4.10: Search facility to explore and search related tags.

4.6 Interactions

In the following, we envision how the core view (ClusterVis) and the two sub views communicate with each other. First of all, every selection performed in SearchTree and TimeCloud changes the underlying data of ClusterVis.

As already explained, with the TimeCloud the user can filter documents by creation date and with the SearchTree one can filter by related tags. There are many ways to combine these three views. In the following, we exemplify one sequence of interaction. The initial state of TagVis is depicted in Figure 4.11. We see all views untouched. ClusterVis shows all aggregate groups and their corresponding documents. The SearchTree shows a bare a list of all tags sorted by frequency and the TimeCloud depicts all tags aggregated by the creation date of the documents. Now, the user decides to have a closer look on the blue cluster in the centre of ClusterVis. She selects the bubble to zoom which results in a view represented Figure 4.12

One can clearly see that the blue bubble exhibit many documents tagged with *d3*. The green bubble is defined by the tag *visualisation* i.e. all documents share this tag. The blue bubble represents resources tagged with *d3*. *d3* and *visualisation* documents are placed in the same cluster because they are similar. There is a pathway among documents tagged with *visualisation* and *d3* which is rather short. By hovering over the different bubble sets the tags which are shared among the documents of a certain bubble are obtained. At some point, the user decides to see only documents which are tagged with *d3*. Therefore, filtering with the SearchTree is applied (as shown before in Figure 4.10). The attention is put on the TimeCloud and zooming into the *month* dimension is applied (as we have explained with Figure 4.9).

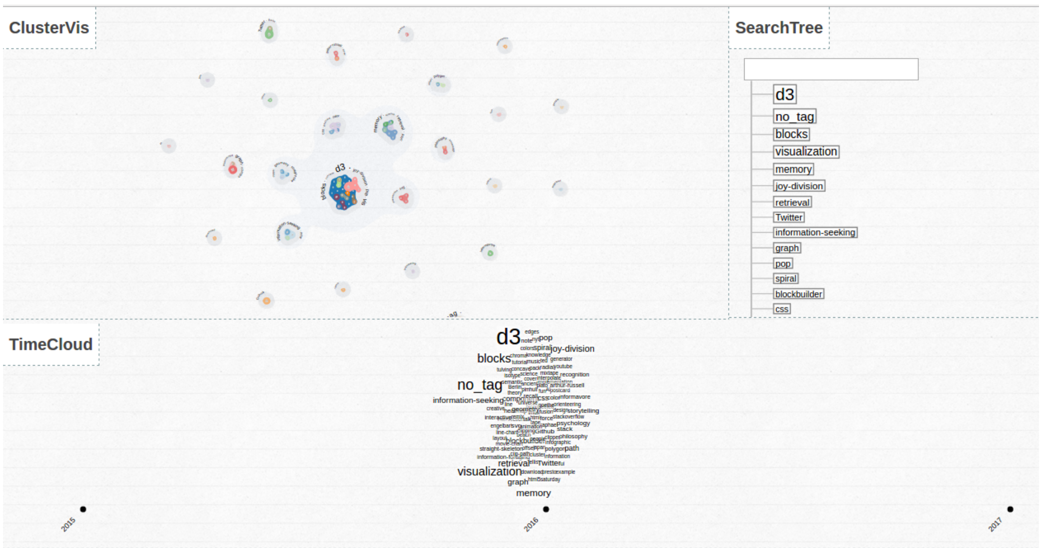

Figure 4.11: Overview of TagVis with the main and the two sub views.

Finally, The user selects the tag *d3* in month March which results in another reduction of the visualised data as depicted in 4.13. Only three documents fulfil the constraint to be tagged with *d3* and created in March 2016. The user can obtain document details via tool tips. With double click one can open the resource.

Figure 4.12: Zoomed-in view of ClusterVis and SearchTree.

Figure 4.13: Final result of the filtering process. ClusterVis shows all documents tagged with *d3* from the month March.

4.7 Evaluation

In this Section, we evaluate our design by handing the prototype into the hands of the user. We let them explore their own personal collection of notes and bookmarks which they created with the Diigo system [9]. Indeed, in theory any tagged data source can be used for TagVis. Unfortunately, tagging is not really widespread for personal information. It was impossible to find participants who already have a complete personal collections organised with tagging. We have chosen the Diigo system as data store. As already mentioned, this application permits the user to organise personal documents in terms of bookmarks, notes and pdfs with tagging. We asked our participants to use it for one month and to perform their daily information tasks e.g. exploratory topic research, fact retrieval, and refinding known items. After one month we performed a preliminary interview to shed light on the initial information needs of our participants. Moreover, we encouraged them to explain their motivation for a search application in terms of Do-Goals and Be-Goals (explained in section 3.2). Only then, we gave them access to TagVis and observed how they attempt to resolve their information needs.

In particular, we made use of the participant observation technique [59]. It is a qualitative data gathering tool. From the preliminary interviews, we derived a search task for each participant. These tasks resembles highly their daily routines and problems regarding information. The observation took place in the environment of the user. We handed the task description to them and allowed a preparation time of only one minute. In this time range, the user can develop some refinding cues i.e the location where the item has been encountered recently or the point in time of last access. We are especially interested in the way they spontaneously choose their actions throughout the interaction process with TagVis. We expect that the user will depend on associations with encountered items to navigate through the information space. After the preparation time, the observation starts. The user tackles the problem with TagVis and we observed arising problems, emotions and remarks. Overall, we put emphasis on so called "Aha moments" i.e. situations where the user is surprised positively and negatively by some insight. They can give hints to the constitution of user stories as foundation for positive user experiences (explained in Section 3.2).

Due to the prototype nature of TagVis, it was necessary to interfere in some situations to help them to escape from some actions. Otherwise, the user might get stuck too often which would turn the overall experience negative. Overall, we tried to be as passive as possible. We only interfered when problems arose or when the user was unclear in their remarks. The detailed study design can be found in Figure 4.14. First, we selected the participants according to the characteristics of the three personas described in Section 3.4. The search for participants was actually quite difficult because we demanded to adopt the Diigo system for one month. Finally, we found three participants suiting the characteristics of the personas namely a retired computer engineer (participant 1), an automotive engineering graduate (participant 2) and a mechanic (participant 3).

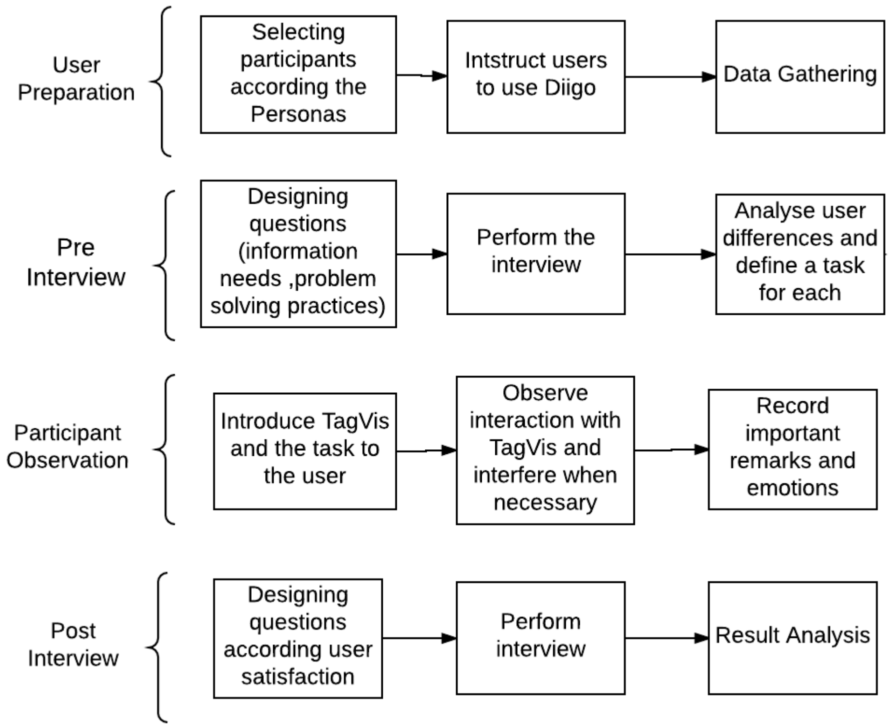

Figure 4.14: Tags aggregated to the month of creation.

4.7.1 Participant 1

Participant 1 is male 56 years old, retired engineer with extensive computer knowledge represents the persona Gerd from Section 3.4.

Preliminary Interview

He can be characterised as a thorough organiser of his personal information. We found out that unlike Gerd, he is not using his personal collection for scientific research. His usage focuses mainly on the organisation of daily administration tasks such as keeping payment information for paying bills or organising bookmarks of contacts of doctors and public institutions. But sometimes he is working on a hobby project regarding his old passion of mechanics which involve a large amount of specific information regarding old manuals and machine specifications.

He uses well-proven patterns in organising his digital files. He applies a folder based organisation scheme wherein the labels capture the content and time dimension. Thereby, he tries to satisfy two contexts at the same time. Moreover, he applies a deep nesting on his folders, especially for his hobby projects. Participant 1 is aware that squeezing two kinds of textual information in labels is not the intended way. It poses many problems. For instance, sorting the folders by time is not really working because the labelled time does not correspond with the time stamp assigned by the operating system. Also deep nesting of different folders often results in duplicate hierarchies which makes it difficult to change them all at once.Concerning his refinding techniques, he likes to browse through his folders to get a notion of what is there and what he needs.

Assigned Task

As the task for the observation we have chosen the relocation of a manual that was the basis of one of his old projects to repair an old motorcycle.

Observation

In the observation, before actually attacking the task, he noted that the task itself is quite vague but he knew that he had to look in the past, perhaps in the year 2012 or 2013. At first, he decides to narrow down the overall selection visualised by the core view with the Time Cloud. Therefore, he selects the tag *motorcycle* in the year 2012 which reduces the visualised documents in all views to some extent. Confronted with less documents, he browses through the core view and detects a bubble depicting all documents regarding the motorcycle brand *Yamaha*. He zooms into it and reviews all documents before he finds the desired one.

We were surprised that he had no problems to filter down the selection for the visualisation. This might due to the fact that filtering works almost like on websites which are using facets. Only the core view with its bubble sets to represent tag groups was a bit harder for him to grasp. After we highlighted that it works similar to Venn diagrams, he could operate this functionality better.

Post Interview

In the post interview, he pointed out that he really liked the interactive filtering with the two sub views (TimeCloud, Dynamic Tree). Unfortunately, the visual metaphor of the core view was unclear to him. Especially, the fact that some tags were grouped together and some are not was not intuitive to understand. Moreover, participant 1 liked the fluid transition between overview and detailed view which can be achieved with zooming.

4.7.2 Participant 2

The second participant is graduate in electrical engineering and 26 years old.

Preliminary Interview

He organised all his resources digitally. He represented the structure of his Bachelor thesis with his folders. He has a folder denoting the introduction, the main part and the conclusion. In each of them he applied nesting to represent different categories of resources which were used for the writing.

Currently, he navigates through the folders to re-track documents. But he would like to have a technique which is more target oriented and faster. We asked why he does not use the directed search facility of his OS. He is not really satisfied with it because the search always results in a bare list of items and he does not really know from which folders the files are coming from. He cannot really place them into context of some task (thesis writing). The most important aspect of a search application is to become competent. He does not like the feeling of being lost and overwhelmed with information. All relevant information for a task has to be certain and easy accessible.

Assigned Task

We did not ask him to simply relocate a file. Instead, we challenged him to summarise his thesis in order to test how the user can retrieve knowledge instead of facts with TagVis. Thereby, the tool facilitates the re-access of personal documents and the reviewing of them in order to bring certain knowledge back to mind.

Observation

The open-ended style of the assigned task resulted in uncertainty how to start the seeking process. He played around with the different views and selecting randomly tags and the corresponding documents to grasp how TagVis works.

We gave him some help how to move from one aggregate tag group to others in the core view. Throughout this process, he rediscovered several relevant tags. Thereby, he was actually ignoring the other two views. The interactive navigation was sufficient to traverse all relevant areas of his personal information space regarding his thesis.

Post Interview

In the post interview, he highlighted that TagVis is not opinionated about how you approach the seeking process. He said that he liked the freedom of modality and not to be limited by only one way of searching. To re-contextualise with content he chose the core view as navigation facility. But he also noted that the visual metaphor is not perfect in the sense that labels around the clusters cannot reflect the whole range of categories involved.

Maybe, one has to take into consideration a way to show some more detailed statistics about the current tag cluster. Moreover, he also criticised the navigation. One can only jump from cluster to cluster which lie next to each other. Sometimes, there are tag clusters which are relevant but not in the current view port and not directly reachable. But he pinpointed that the visualisation of the core view is more expressive than Tag clouds. Especially, the ability to zoom into some isolated areas of the information space and inspect some related tags was really intriguing. He said that he never approached his personal collection from this perspective.

4.7.3 Participant 3

The last participant is female, 18 years old and a professional mechanic.

Preliminary interview

During the interview she explains that she is using her personal collections of documents only for casual contexts. In particular, she keeps shopping lists of items she is interested in. For instance, she plans to buy accessories for horse riding. Therefore, she needs to compare the quality of certain products and their price-quality ratio. She applies a rather complex taxonomy to categorise products regarding their use case and type. For instance, horse hoofs differ for which context they are used (working purposes, artistic exercises, transportation). Concerning her seeking activities, she focuses on speed. She is a frequent user of directed keyword search and likes to browse through lists of items very fast.

Assigned Task

The task we presented to her is to find the cheapest saddle for transportation purposes.

Observation

Confronted with the task she held still for a second and reflected about the candidates. Then, she instantly focused on the search field of the dynamic tree and searched for *saddle* before narrowing down further by selecting the related tag *transportation*. The result has around 30 items. In this moment, she was trying to apply a full text search by title of documents. We had to tell her that this functionality is not yet incorporated. She sighed disappointed and began to browse through the core view with its clusters which exposed further sub categories such as typical saddle brands. But one could see that she was not really comfortable with this kind of navigation i.e. zoom into a particular cluster and then move to neighbouring clusters. It took her some time to relocate the perfect item.

Post Interview

As to be expected in this interview, she expressed that she really would like to jump to a particular item of interest directly instead of filtering down the results step by step with tags. Moreover, she criticised that the navigation of the core view with zooming and selecting bubble sets was a bit cumbersome and could not compete with the speed of reviewing simple lists

4.7.4 Analysis

Whereas the participant 1 liked the novelty of TagVis to interact with personal collections, participant 3 was not really looking for a navigation technique that fosters exploration. This contrast highlights the general problem for visual search tools. It is difficult to support directed and undirected seeking behaviour at the same time. The wide variety of possible ways how to approach a target results often in a lack of efficiency. How to serve these two contradicting aims successfully is a challenge which cannot be solved methodologically beforehand. One has to decide to which degree of exploration and directed search need to be supported. There is a tension in between these two poles. The heavy support of one results often in a lack of support of the other. Moreover, we think that the two first participants were a bit biased by the visual representation which appealed to them. Therefore, they looked over usability issues and more profound navigation issues (which were highlighted by participant 3). It is obvious that TagVis needs to be improved in this area.

On the other hand, the visual representation is quite powerful when grasped correctly (participant 1 and 2 had slight problems and participant 3 was not even interested in understanding it). It permits to gain an overview of one's personal collection and can be used to express a focus gradually with zooming. Compared to standard Tag Clouds, the core view (ClusterVis) give insight into similarity and relatedness of tags. Moreover, the user can still overview the whole information space because the labels of the groups depict frequency by font size.

5 Theory and Implementation

This Chapter gives account to the *tag graph* functioning as the underlying navigation structure of the views presented in Chapter 4 and highlights some implementation challenges.

5.1 Tag Graph

Starting point of TagVis is to make sense of the relatedness of tags. Therefore, a graph structure is abstracted from one's personal information space. As already highlighted the only requirement for these documents is a set of tags. We define a *tag graph* as follows. First of all, we consider the information space as a collection of documents. Each of them exposes a set of categories called tags. For each unique set of tags a node is created. One node can represent several documents. These nodes are connected by edges if and only if they intersect in the tags they use (do they have one or more tags in common). Such a graph is likely to consist of several connected components, in some cases they are even biconnected.

In graph theory, a connected component of an undirected graph is a subgraph in which any two nodes are connected to each other by paths, and which is connected to no additional vertices in the supergraph [11]. On the other hand, biconnected components are stronger connected components in the sense that when one attempts to remove a node or an edge of such a component it stays connected. Figure 5.1 visualises such a tag graph consisting of 100 documents. One can see that there are many nodes of unique tag sets sharing the tag *d3*, depicted by the cluster in the upper part. Besides this, there are few other connected components (most notably the component based on *memory* in the lower left area). Unfortunately, one cannot gain any insight into the structure of the *d3* cluster because there are too many links involved. It is impossible to derive any insight of this hairball. We assume that the user organises her documents according a logic which at least contains more general and more specific tags.

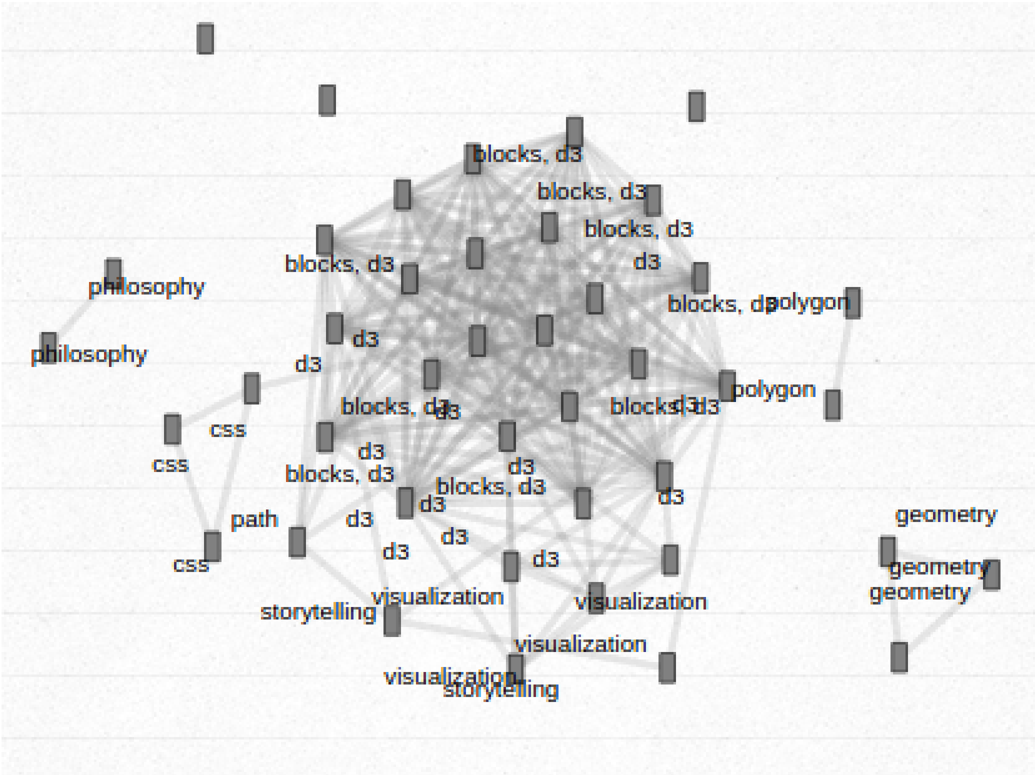

Figure 5.1: Tag graph of a personal collection of bookmarks.

5.2 The Hidden Hierarchies of the Tag Graph

How to reveal the hidden logic of one's personal information space? In [3, 78], the authors have shown that in large collaborative tagging systems navigation is an issue because the relations between these tags are too manifold. It is hard to move from a broad tag specifier to a more narrow one. Therefore, they developed a technique to abstract hierarchies from these systems which facilitates the overall navigation. The resulting algorithm uses centrality as the main metric to find more general tags which is defined as the shortest distance to any other node.

We adopt their general idea to derive hierarchies and translate it into the domain of information visualisation. One important difference is that we do not use the same graph model. Whereas Hey use each unique tag specifier as a distinct node we consider unique tag sets. A tag set is a combination of tags used to categorise an information item. If one only considers single tags as nodes then it is impossible to derive unique positions for visual elements representing the data elements. We use the following definition for the centrality of a document.

$$\frac{|edges(n)| \cdot |documents(n)|}{|tags(n)|}$$

Figure 5.2: Centrality metric to determine the generality of a tag set node.

edges(n) is defined as the number of edges to other unique tag set nodes. Two tag sets are connected if the intersection of them is non empty. For instance, the tag sets *[thesis, visualisation]* and *[thesis, research]* are linked because the intersection is non-empty namely *[thesis]*. *documents(n)* is the number of documents which exhibit the unique tag set. And finally, *tags(n)* is the cardinality of the unique tag set. For instance, *[thesis, article, d3]* has the cardinality of three.

We assume that a lower cardinality of the tag set denotes a more general categorisation. For instance, *[thesis, d3, library]* is a more specific categorisation than *[thesis]*. But we did not simply choose the tag set length to measure generality because of two reasons. Firstly, there are tags which only occur in combination with others. Then a node with one tag and one document would be ranked higher as a node with several tags and documents. Secondly, a node with a large tag set is more likely to have more connections than a node with a smaller tag set. But it is not necessarily the case. For instance, when each tag in a tag set is only used uniquely in this set then it has zero edges. This metric assigns a higher importance to nodes which have a high degree and contain a large set of documents which are categorised with few tags. For instance, for the graph in Figure, 5.3 the most general node is $[d3, geo]$ because it consists of two tags and has three edges to the other nodes. The corresponding calculation looks like this:

$$\frac{|edges([d3, geo]) = 3| \cdot |documents([d3, geo] = 8)|}{|tags([d3] = 2)|} = 12$$

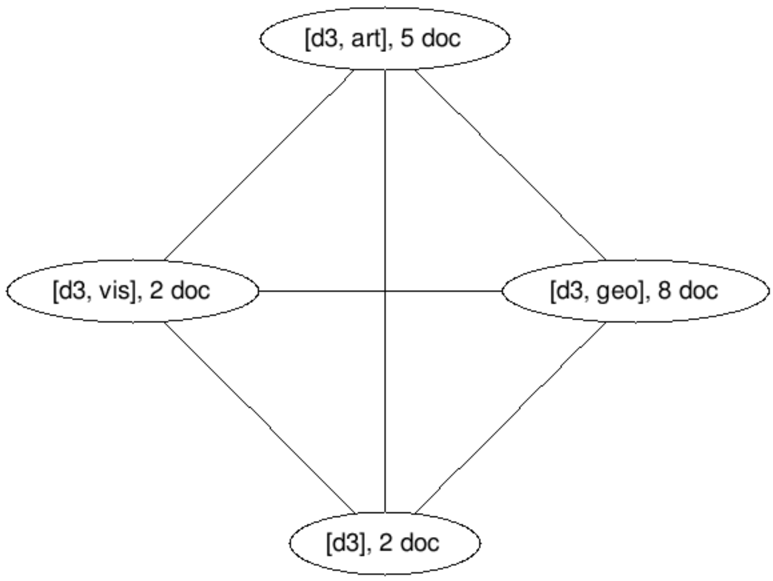

Figure 5.3: Example graph to find the most general tag set node.

In order to extract the final hierarchy one has to traverse the tree to produce a total order. We use a *breadth-first-search (bfs)* approach to gather all current children of a specific node. Then, the order of children to be visited is determined by the metric explained before. The algorithm to derive one hierarchy from a specific start node is depicted in algorithm 1. To derive all hierarchies of the tag graph one has to execute the algorithm 1 on its connected components.

Last but not, least the messy tag graph from Section 5.1 can be translated into the graph depicted in Figure 5.4. This graph is acyclic and represents a collection of hierarchies. This data structure is crucial to apply the Bubble Set technique for the core view ClusterVis in Section 4.5.1. It places general documents with many links in the centre of its neighbours.

Algorithm 1 Hierarchy Derivation.

```
procedure
    graph ← [nodes, edges]
    hierarchy, stack ← [ ]
    stack.push(determineStartNode(graph))
while(stack is not empty) :
    u ← stack.pop().
    hierarchy.push(u).
    vs ← getNbsByTag(u).
    sortedVs ← sortByMetric(vs)
    stack.concat(sortedVs)
```

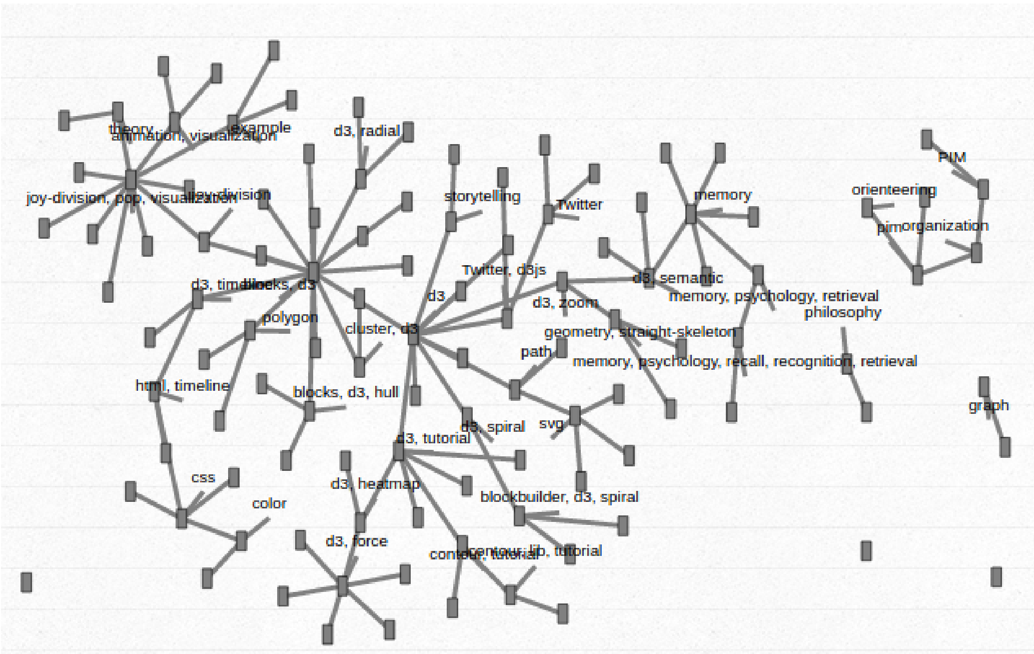

Figure 5.4: the reduced tag graph based on algorithm 1.

5.3 Implementation Architecture

The architecture of the implementation follows the Information Visualisation *data state reference model* [28]. The basic idea is to structure all implementation components in a data centric way. Figure 5.5 shows this organisation.

The *value* stage represents the raw format of the data. Here, the data elements (documents) are analysed and grouped according to several attributes (single tags, tag sets, time date). The result is not yet mappable but it contains all information that will be presented on the screen. The *analytical abstraction* stage further reduces the data into a format which can be visualised directly. Here, the analytic abstraction is transformed into the complex tag graph. This graph is traversed and transformed into a directed acyclic graph with the algorithm 1.

Finally, this graph is used to find the ideal positions for the documents according their membership to unique tag sets. The *view* stage produces the final visualisation. Here, we use a force layout to push each document to the preferred location. Thereby, we apply collision detection for the documents and their corresponding clusters in order to minimise overlapping. The implementation is completely based on web technologies, especially SVG. To facilitate CRUD operations we use *D3* [22] which is also used for layouting the tag graph. In order to facilitate the speed of rendering, we outsourced the computation on an external server. The client uses the precomputed positions for tag sets for the corresponding information items (single documents).

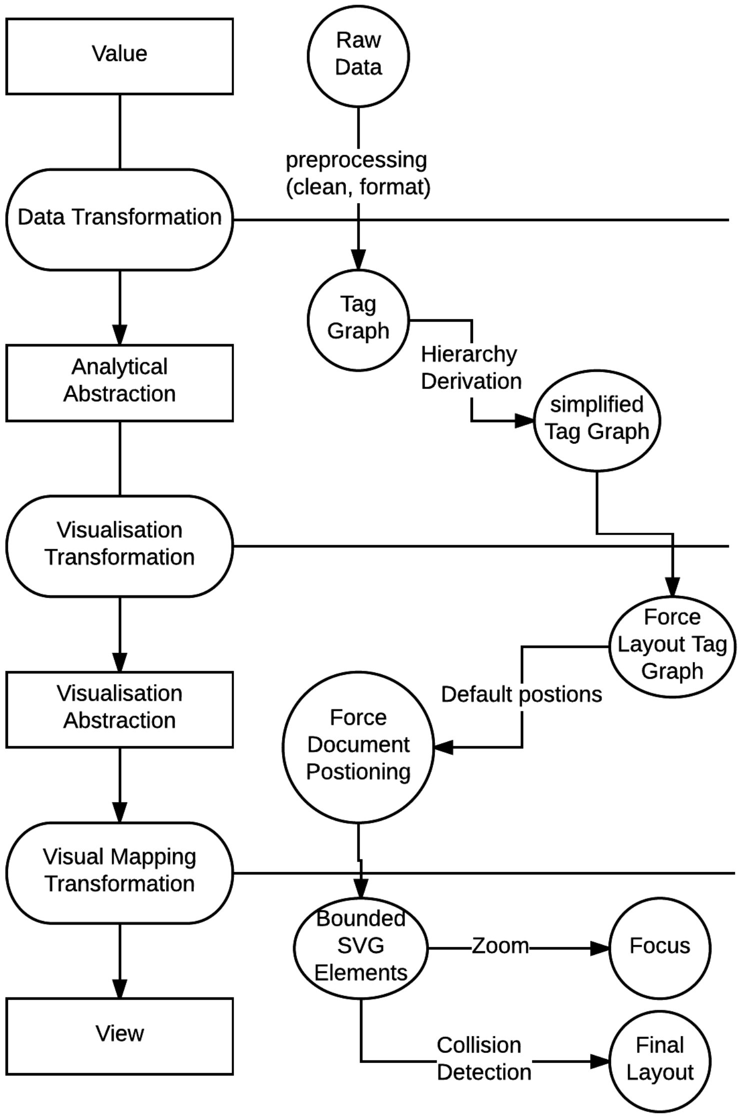

Figure 5.5: Data state model by Chi applied on the implementation architecture of TagVis.

6 Conclusion

In this last Chapter, we recapitulate the contribution of the project to introduce a new visualisation technique for tagged data structures. Now, we will exemplify how to generalise the solution from the personal information context to other use cases.

The aim was to find a novel visualisation technique for unstructured data based on tags or keywords to foster exploration. First, the notion of exploration in context of information seeking was examined. Then, an overview of classification schemes was given for physical and digital environments. For the latter it was shown how they can be interfaced by the user. Thereby, we noted that in the case of tagging the lack of an explicit structure results in challenges concerning navigation and therefore exploration.

In Section 3, the domain specific characteristics of information seeking regarding personal information were isolated. In particular, the exploratory seeking behaviour according to Marchionini and Dörk et al. was translated into a new context. In Chapter 4, we designed the views of TagVis (core view: ClusterVis, sub views: TimeCloud, SearchTree). ClusterVis functions as the core view of TagVis and introduces a novel visualisation technique. It combines the node-link and aggregate approach. It clusters similar tagged documents in one area and keeps links to other related clusters. With this technique, it is possible to visualise highly interconnected tag spaces. A pure node-link approach would fail because it introduces too many links which would result in a bad readability. Moreover, It is superior to a tag cloud based approach because of the following reasons. Firstly, it depicts the subset relations (intersections) among sets of documents. Secondly, the proximity among clusters denotes a similarity. It must be noted that ClusterVis is not bound to the visualisation of tags, it can be applied to any other set domain. Thirdly, through the integration of a zoomable user interface, ClusterVis is better scalable than pure Tag Clouds. Last but not least, it depicts the tagged documents directly in the visualisation and does not aggregate them into textual strings. Thereby, documents can be reviewed in place with tool tips for instance. Also, it is imaginable to zoom directly into a document to access the content in full scope.

Another design driver was the need to join information exploration techniques with more directed seeking techniques. One of the key challenges was how a tool can support fast retrieval of documents but at the same time more open ended navigation techniques which foster interest and stimulation.

6.1 TagVis in other Domains

Indeed, the development of TagVis focused on the PIM domain. But its minimal data model makes it possible to adapt the visualisation to others domains as well.

Similar to online services that create a profile of one's social interactions on the Web, TagVis can be used to aggregate data from various other sources. Thus, the user can be enabled to explore the intersections between tags which exist between platforms. This is a really powerful feature because it tackles not only the information overload problem but also the Information Fragmentation problem is addressed. Consider a typical user who keep emails in Gmail[1], notes in Evernote[2], calendar entries in Apple Calendar[3] and publications in dedicated document management software. Making sense of this disperse personal information is a non trivial task. Often fragmented information results in a fragmented memory. Documents sharing a common context cannot be detected as such because they exist in different environments. For instance, the project of writing an scientific article involves different kinds of information such as emails by befriended scholars, notes and related articles. The fact that something written in a note cannot explicitly reference an article makes the whole activity more complex. This fragmentation grows when people are confronted with a wide range of information scattered through-

[1]https://mail.google.com/
[2]https://evernote.com/
[3]https://www.apple.com/osx/apps/#calendar

out different tools and different media. TagVis can help to join information from different sources and present them in one homogeneous view such that association can be operated freely to construct a consistent mental model.

6.2 Exploration and PIM

As one of the first we intended to combine these two "contradicting" disciplines. A lot of effort went into a literature analysis to reveal that searching in personal information is often based on uncertainty. Maybe it is less than in domains which deal with completely unknown information but one cannot simply fall back into the Query-Response paradigm. The search application needs to open up an interactive discussion between the user and the information sources. Therefore, visual exploration techniques can be powerful tools. They provide a sense of location which facilitates the development of a mental model of the information space. But one should also tailor exploratory techniques to the case that the information need is certain. Thereby, well established query-response techniques like keyword search or filtering facilities can be adopted. In Section 4.7, we found out that these two paradigm of seeking are to some extend contradictory because exploration is based on a fluent transition or movement in the information space whereas directed search facilities behave teleport alike. An harmonic integration can be achieved when the search results are organically presented to the user with the help of animations. Then, the user does not lose their context when jumping into a small area of the information space. The preservation of context is crucial for understanding the search results. If the user does not see intuitively why the results satisfy their information need the results are of no value.

6.3 Future Work

In the following, we will review missed opportunities for the design and development of TagVis. We will start with subtle more technical improvements before we discuss more conceptual shortcomings. TagVis uses a zoomable user interface to make set relations among tags more visible. Unfortunately, it is not yet really semantic. The plan was to replace the document surrogate with a complete view of the data element when zoomed in. This feature would have been really powerful because the user could interact with the underlying document directly instead of accessing it via a hyperlink. We started the implementation purely with SVG. Theoretically, SVG offers the functionality to embed a wide range of data formats such as images or HTML elements. In practice, the integration is far from optimal in modern browsers. Moreover, the views of TagVis are not yet perfectly synchronised. In some cases, the SearchTree cannot reflect changes made in the TimeCloud. To fix this problem some parts of the architecture need to be rethought. Especially, the interface between the three views needs to be improved. Right now, they expose a big part of their internal states to the outside world which is not a good design pattern. Also, in terms of performance, there is room for improvement. The derivation of the reduced tag graph (Section 5.2) is quite expensive. Depending on the size and the connections in the tagged input data, the initial computation of TagVis can vary a lot. We already identified some performance bottlenecks. For instance, the initial layout of the core view is only computed once. Successive filtering actions correspond to removing nodes and edges of the underlying tag graph. This is a lot faster than recomputing the layout on every user interaction.

Another issue concerns the layout of the Tag Graph. We said that we derived hierarchies which in turn correspond to directed acyclic graphs. To highlight hierarchical levels this type of graph can be visualised with layered layouts. We made some experiments with the Dagre library [4] to respect the hierarchical levels. Unfortunately, it performed quite poor in terms of space efficiency. As an alternative, we also explored the possibility to include an additional constraint in the underlying force layout. The formula would be similar to the following formula:

$$\forall v, w \in \mathit{Nodes} : \mathit{level}(v) > \mathit{level}(w) \Rightarrow \mathit{positionY}(v) > \mathit{positionY}(w)$$

$\mathit{level}(v)$ denotes the level of a particular node in an hierarchy. Thereby, any node with an higher level will positioned higher on the canvas. Unfortunately, this idea did not pass the initial conceptual state.

The evaluation in Section 4.7 is of qualitative nature. It suited our aim to reveal the quality of exploration in terms of User Experience. But in order to make a stronger statement about the benefits of TagVis we need to perform a quantitative evaluation. Perhaps, a questionnaire based survey with subsequent statistical analysis could be more meaningful.

The original idea was to develop TagVis for a touch interactive tabletop system. Unfortunately, this aim could not be achieved due to several reasons. First of all, much work was invested into the quality of visual representation. Interaction facilities are in place but not yet brought to perfection. Currently, only desktop interactions are supported. It is difficult to develop a visualisation technique from scratch for a tabletop device when much time need to be invested in the data processing phase. Nonetheless, our design

[4] https://github.com/cpettitt/dagre-d3

methodology can be easily extended with another phase to tailor TagVis for interactive tabletop displays. The fact that the core view (ClusterVis) is based on a zoomable user interface makes it a natural fit for larger displays. Then, the user could even navigate larger information spaces without being overwhelmed by too much data per pixel. Even, the relationship between the user and the information space can be made closer by applying well known gestures like pan and tap. Figure 6.1 exemplifies the wide range of possible gestures on tabletop displays. Furthermore, it also highlights its social component in terms of interactions with other user. This aspect was out of scope of this thesis. But it is imaginable to divide the canvas of ClusterVis view into two parts to establish some kind of comparison view that works with special visual markers to highlight similarities.

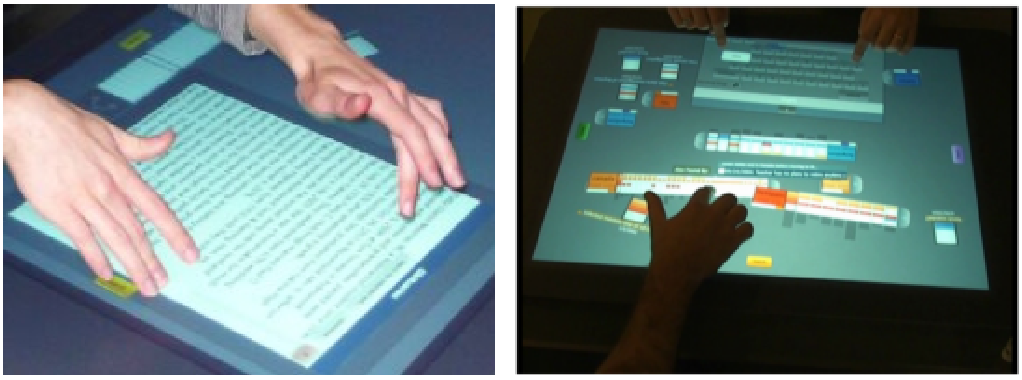

Figure 6.1: The possibilities of a tabletop display in terms of interaction.

The development of TagVis has not stopped here. First, we will try to fix the most important bugs which disturb the User Experience. Second, we are eager to develop data preprocessing modules for other social web platforms in order to gain a complete view of one's personal information space.

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