InfoVis Experience Enhancement through Mediated Interaction

Sarah Faisal, Paul Cairns, Brock Craft
University College London Interaction Centre (UCLIC)
Remax House, 31/32 Alfred Place
London WC1 E7DP, UK
+44 (0) 207 679 5225
{s.faisal, p.cairns, b.craft} @cs.ucl.ac.uk

ABSTRACT
Information visualization is an experience in which both the aesthetic representations and interaction are part. Such an experience can be augmented through close consideration of its major components. Interaction is crucial to the experience, yet it has seldom been adequately explored in the field. We claim that direct *mediated* interaction can augment such an experience. This paper discusses the reasons behind such a claim and proposes a mediated interactive manipulation scheme based on the notion of directness. It also describes the ways in which such a claim will be validated. The Literature Knowledge Domain (LKD) is used as the concrete domain around which the discussions will be held.

Keywords
Information Visualization, User Experience, Direct Manipulation, Multiple Input Devices, Mediated Interaction

1. INTRODUCTION
People vary in the ways they process data and gather information, therefore the same visualization maybe perceived differently by different people. In addition, people may have different goals when it comes to using the visualization. Information visualization (InfoVis) is not about seeing; it is about the experience that each active participant gains. By giving participants the right set of tools, aesthetic and interactive, higher levels of such an experience maybe reached, resulting in a better gain. These factors imply the need for users to be allowed to freely communicate with the visualization at hand. Here, freely implies that the manipulations need to be conducted in a way that would result in reducing users' interaction cognitive load, and increasing user cognitive engagement. Current widget-based direct manipulation systems do not reflect such a concept; for example, rotating an object cannot be done directly by a mouse. We propose a multi-input device and a task-specific, interaction scheme, which we refer to as *mediated interaction*.

When creating a complete InfoVis experience, various components are to be taken into account starting with the users themselves. It is quite crucial to understand the information that users perceive when working in a specific real-life context, such a general understanding is required since it will be the bases around which the visualization will be created and tested. The Literature Knowledge Domain (LKD) will be used as the application test bed. Aesthetic features should also be considered, since they are the means through which information is perceived. Last but not least, the interaction method should be seriously considered, since it is the only way users can communicate with the visualization. The testing of whether the visualization truly reflects an experience involves both qualitative and quantitative measures due to its cognitive nature. A proposal as to how such may be achieved will be presented.

2. VISUALIZATION IS NOT "SEEING"
InfoVis can not be defined as merely the visual representation of the data, since InfoVis includes within it meanings that go beyond the visible aesthetic characteristics of an interface. It is more properly understood as an activity in which users are cognitively engaged with the potential of gaining an insight and an understanding of the represented data [36]. In other words, users are active participants in an engaging cognitive event. InfoVis is an *experience* that leads to the gaining of knowledge. To further discuss InfoVis as an experience, two dictionary[1] definitions are relevant to the matter at hand:

Experience: The apprehension of an object…through senses or mind

Experience: An active participation in events or activities, leading to the accumulation of knowledge or skill

The nature of this participation is characterized by the fact that information is continuously being perceived and re-perceived in a process of *cognitive engagement*. Information *cannot be seen*, rather, it is interpreted by users from the represented data [40]. Information and data are not equivalent, as Bertin [3] emphasises. He describes information as being the revelation of underlying relationships between the data. Information is derived from the data as Spence [35] indicates. It is through the manipulation of the represented data that more information can be revealed, hence the need for users' active participation. InfoVis is not *seeing* since

[1] The American Heritage Dictionary

information cannot be seen. It is, in fact, an experience wherein both the aesthetic aspects and the interactive aspects take part. With this understanding, InfoVis can be defined as the process of mentally converting the represented data into information. The data needed to be explored and re-explored for additional information gain, as Cleveland ([15], quoted in [36]) describes:

"Graphing data needs to be iterative because we do not know what to expect of the data; a graph can help discover unknown aspects of the data, and once the unknown is known, we frequently find ourselves formulating questions about the data"

It is impossible to determine in advance what can be inferred from the data unless it is examined and re-examined from different perspectives. The more the data is manipulated the more knowledge and insight will be gained on the information it portrays. This gained knowledge introduces a new set of questions, causing a re-examination of the data, in an iterative, exploratory process, making interaction a major part of the *visualization experience*.

3. MAKING AN EFFECTIVE VISUALIZATION EXPERIENCE

It is hard to find an effective InfoVis system that is in itself an *experience*, where the represented data, the aesthetics and the interaction are all taken into account. Several factors must be taken into consideration when designing for an effective InfoVis system experience: understanding real user experience in a related context, effective aesthetics, and effective interaction.

3.1. User Experience

User everyday experience in real-life related context must be the primary focus when it comes to developing an InfoVis system. The knowledge gained from the understanding of such an experience is the basis of the information that should be reflected in the system. Often in InfoVis development processes, such an understanding rarely takes place rather, requirements are simply gathered. Taking as an example the Literature Knowledge Domain (LKD), much research has been conducted in developing visualizations that would better represent information, such as authors, articles and their interconnected dependencies, in order to assist researchers in working and making sense of their literature. However, such research does not really reflect users' experiences in such a domain. The main goal behind these studies is to find algorithmic solutions to the ever growing size of knowledge domains. These studies fall in two categories: investigation of new interactive metaphoric visual representations, or exploration of reduction and minimization algorithms. These studies, described below, do not really reflect the researchers' intentions for such an application domain even though they are the primary users. Important questions were not considered in such studies:

How do people make sense of their literature?
How do people actually work with literature?
What difficulties do people face when working with literature?
...
These considerations received little attention. However, they are of great importance in reflecting users' day to day experiences and needs in such a context. It is important to understand the information that users need to *experience* when interacting with InfoVis system.

3.1.1. Visual Solutions

It is clear from the readings of some studies done in the field of representing the LKDs that the main intention behind them was not to actually assist users in making sense of and working with their literature. Rather, the point of such studies was the development of new interactive visual metaphoric solutions for representing large amounts of interrelated information. In other words, the application domain was not in itself the problem, but instead, the problem being addressed was how to represent large amounts of interrelated information in an understandable and usable way. Seminal examples of such work are SemNet by Fairchild et al. [19] and their syntactic 3D representation, Butterfly, by Mackinlay at al. [28] with their organic interface, and GRIDL by Shneiderman et al. [34] with their idea of categorical grouping.

Such visualizations use literature metadata, such as: article title, number of pages, author names etc, as basic visual entities. Direct relationships between these entities are also represented, such as: which articles cited which, who collaborated with whom, etc. Mackinlay's Butterfly is a classic example of a literature metadata visualization, where articles and their associated citation links are represented. Articles are represented as butterflies. Each butterfly has a left and right wing, where wings represent citation links between documents.

Due to the underlying goal of such studies, all usability assessment was based on testing the efficiency of the interfaces. Efficiency meant the speed in which users could find documents, in addition to the usability of the interface itself. It was also noted from the readings that there is no consistency in the represented entities among the different studies. Some studies represent the article, others the articles and the authors, and some represent number of pages while others don't, etc. This is due to the fact that few user studies were conducted to gather users' requirements and experiences. There are some exceptions to this. However, in most cases the interfaces did not totally reflect these requirements.

Envision [30] is a tool used to display search results. In contrast to the other studies, they first started by trying to understand how people worked with literature. Results from these studies showed that people needed to identify information such as: underlying relationships, trends, emerging topics, and how influential a work is. Usability studies have been conducted around the graphical view itself to test whether users could understand the displayed results and locate the desired documents. These studies, like the others, concentrated more on the usability of the interface and not the information it revealed.

CiteWiz [18] is another tool that also represents bibliographic information. The researchers also began their study with extensive discussions with six active researchers in a focus group. They used a pre-existing visualization technique that they had previously developed known as the Growing Polygons Causality visualization technique [17]. Articles and their citation relationships were represented, but not the authors. Authors were not represented even though they were an important part of the user requirements. The reason for this was that it was impossible to represent the collaborative relation between them in such a visualization concept. Therefore, it can be concluded that in such a case it is the user requirements that were reduced in order to satisfy the visualization needs and not the other way around. This reinforces the findings from the other studies, that it is the visualization technique in itself that is the challenge.

3.1.2. Reduction Solutions

Another trend of research done in the field of representing LKDs concentrates on the visual representation of the underlying semantic structures. In other words, they rely on representing similarities in meaning. Nodes representing documents are grouped according to their similarity [12][14]. In such visualizations, algorithms such as Latent Semantic Indexing (LSI) [16] are used to extract salient patterns from collections of documents. These patterns are then used to visually represent citation patterns, such as the evolutions and significant contributions within a knowledge domain [13]. In such cases, entire citation domains are visualized, therefore relying very little on interaction.

Such studies claim that the systems facilitate the searching of important papers in a domain. However, there is no evidence, up to this point, of any user studies to back up such a statement. It can safely be generalized that this type of research, which relies on extracting and representing content similarity and evolution patterns, relies very little on usability studies. It is the exploration of how such algorithms could be applied to large knowledge domain visualizations that is the intention of such studies and not the reflection of user needs in such a context.

3.2. Effective Aesthetics

Visual aesthetics and representations play a major role in InfoVis systems, since they are the entities and tools that allow for information portrayal. Major research in the field of InfoVis places a lot of emphasis on such representations, where systems are being developed with the goal of pushing the boundaries in finding novel and interesting representations. Designers and perceptual psychologists have laid clear guidelines (e.g. Bertin [4] and Tufte [38][39]) when it comes to the aesthetics. However, there is no obvious research where such assertions have been validated. Therefore, it must be emphasised that usability testing is needed to ensure that users fully understand the visual queues, in addition to the metaphoric representations, as will be discussed in section 4.2.

3.3. Effective Interaction

A less studied, yet equally important, component of InfoVis systems is interaction. It is through interaction that users communicate their requests and manipulate the visual representations, therefore gaining additional insights of the data. Users are constantly learning, discovering and revealing information, in other words *exploring*. It is this *exploration*, as Shneiderman [32] puts it, which allows users to better comprehend the data and gain information. Interaction is the means by which users can explore the data, making it essential to the visualization experience.

Shneiderman's [32] Visual Information Seeking Mantra (over-view first, zoom and filter, details on demand) emphasises such an idea, where he stresses the importance of the availability of manipulative tools. It is these tools that allow for the seeking and discovery of information. Due to the complex nature of the data being represented in most InfoVis systems, not all information can be portrayed in a single static view. As a result, data manipulation, and hence, interaction becomes central.

Since this research is interested in InfoVis as an experience, it is of crucial importance not to break the flow in the users' cognitive engagement, described in section 2. The intent is for users to be able to naturally and directly interact with the visual representation in a manner that would allow for such to take place. Direct manipulation offers a promising solution.

3.3.1. Direct Manipulation

Input devices are the means by which humans communicate with computers. They comprise a main entity in human-computer experience. This goes back to when graphical user interfaces were first introduced in the 70's and 80's through Xerox Star [35], where the basic style of interaction was, and is still, known as *direct manipulation* [23][31]. Users directly manipulate objects of interest by clicking, dragging, scaling etc. Such an interaction style has been very successful over the past years. This is due to the fact that such an interaction style takes into account associations based on natural human skills, such as, point, move, drag, etc [26]. Due to the naturalness of this interaction style, users engage with the interface in a comfortable and less stressful manner [33], reducing associated cognitive load.

However, such a concept is challenged when it comes to interacting through generic input device. It is the generic nature that causes for it to be inappropriate for certain tasks, resulting in the need for onscreen widgets. On screen widgets break the notion of direct manipulation [2], since users must interact with the widget instead of the object. For example, when using a mouse the only way a document can be scrolled is through the on screen scrollbar widget. Thus, the widget acts as a proxy for a real world object. However, users can directly manipulate the document using a mousewheel, since such a device fits the scrolling activity. This generic-widget interaction scheme challenges the true meaning behind direct manipulation since it breaks the interaction flow, hence the users' cognitive visualization engagement. The breaking of this interaction flow during users' cognitive immersion with the visualization might, as a result, affect the visualization experience [8].

Eliminating these widgets and allowing for objects' direct manipulations creates a need for input devices that match the tasks at hand. Since visualizations are complex, *direct* object manipulation done through a generic input device would be impossible due to its inappropriateness for certain tasks. This leads to the idea of using multiple specialized input devices, which we refer to as *mediated* interaction. The idea is for the input devices to act as direct mediators between the human and the computer. Hence the term *mediated*. As a result, users would be able to communicate their requests to the computer through direct manipulation, therefore not concentrating on the tool. This parallels Heidegger's [22] notion of "readiness-to-hand", which refers to the fact that when people work with a tool they almost treat it as invisible, focusing instead on the task at hand.

3.3.2. *Mediated Interaction Vs. Ubiquitous Computing*

Several studies have been built around the idea of using multiple specialized input devices. They touch upon the idea of Graspable User Interfaces. These studies are built around the notion of attaching physical artefacts to virtual objects. As a result, virtual objects can be *physically* directly manipulated, emphasising the idea of *direct* manipulation. At a first glance, such studies resemble the basis of the work being proposed by this research. However, they differ in their essence, because they spring from the concept of ubiquitous computing, which is not the aim of this research.

The overall concept behind Graspable User Interfaces might seem quite affiliated with what is being proposed by this research, since they both arise from the concept of using multiple input devices. However, they differ in the applicability of their target domains. The differences will be presented as part of the discussion of some seminal work that has been done in the area.

Fitzmaurice et al [20] introduced the notion of Graspable User Interfaces in Bricks. In such an interface, physical artefacts that look like bricks are used to manipulate virtual objects. The bricks operate on a horizontal display which looks like a desk, "ActiveDesk". The bricks can be thought of as physical handlers that are attached and detached to and from virtual objects, simply by placing or removing the brick over the virtual object. Therefore, virtual objects are manipulated by simply manipulating the physical bricks, allowing for a seamless blend between physical and virtual objects. Here is where the fundamental difference appears, in that they are aiming at digitizing the physical objects themselves. It is important to note that the digitization of physical objects is not the aim of this research.

Fitzmaurice and Buxton [21] performed three experiments in which they had users associate a physical device to a virtual object. The first one used physical devices that looked exactly the same as the displayed virtual objects. The second one used generic devices that were equal in number to the virtual objects, and were asked to associate each with a virtual object. The last used a generic device, where it was required to associate it to several on screen objects. They proved that users had performed better when associating multiple specialized input devices. It is very important to note that what is really meant by specialized here is that the devices resembled in form the objects on the screen. This is another fundamental difference, where specialized in such research is related to the physical resemblance of the on screen widget and not the task at hand.

Research in the field of Graspable User Interface originates from the idea of using multiple input devices. These devices are used to directly interact with virtual objects. It is important to note that in such a research domain the spatial orientation and affordance of the physical objects are part of the interaction goal. This is because the main goal behind such research is the digitization of physical objects. However, in this research, input devices are not the goal of the interaction; instead they are the means by which the goal gets attained.

3.3.3. *Positioning Mediated Interaction*

The goals of Graspable User Interfaces are along the lines of Weiser's notion of ubiquitous computing [41], in which the aim is for computation to be embedded in everyday objects. Such an idea is also reflected in tangible user interface research, where virtual information becomes tightly coupled with physical objects. This can be seen in examples such as Wellner's [42] DigitalDesk and Ishii and Ullmer's [24] TangibleBits. However, such concepts are not the aims of this research.

The proposed idea lies in between a complete in-the-box and a complete out-the-box interaction scheme. What is meant by in-the-box is that all manipulation is done through widgets embedded in the screen. What is meant by out-the-box is that virtual information becomes part of the physical world. One of our objectives is to bridge the gap between the virtual object and the user's direct manipulation. These devices become the *mediators* between the user and the virtual object.

4. PLANNED RESEARCH

The main question this research will attempt to answer is: Can *direct* interaction through the use of *mediated* input devices augment LKD *visualization experience*? Various studies need to be conducted to explore the dimensions that the answers to such a question may have. However, before explaining the detailed steps we plan to undertake in this research, it is important to clarify the reasons behind choosing LKD as an application.

The LKD is applicable to the main problem of this research since it is an *experience*. Researchers work with literature differently; what they discover and how they make sense of literature differs from person to person. The more they work with literature the more they learn and the more knowledge they gain. The diversity of ways in which researchers work and make sense of their literature makes it an even more appropriate and challenging application domain. This area is close to every researcher, making possible solutions widely applicable. In addition, such a domain is closely related to the digital library work going on at University College London Interaction Centre (UCLIC). This allows for such work to be part of UCLIC's research interests.

4.1. Semi-Structured Interview

The information that a visualization portrays is crucial to the experience that it yields. Therefore, is important to understand how researchers work and make-sense of their literature. In order to gain such an understanding we are currently conducting semi-structured interviews with researchers of different backgrounds. The analysis and information gained from these interviews will be used as the test bed around which the tool will be studied. The interviews are conducted with novice researchers entering a new field, experienced researchers, and experienced researchers entering a new field. The subjects come from HCI and Psychology backgrounds.

These interviews are being recorded and transcribed. They are being analyzed using the Grounded Theory [37] approach. As a result of this analysis new categories and meanings are being discovered. An example of such findings is that subjects view authors as a group of articles, and that articles are inseparable from authors for example, when asked:

Interviewer: *"How would you define an influential author?"*
Subject1*: "… I guess I would look at the number of citations… I would look at journal status…"*
Interviewer: *"What about an influential article?"*
Subject1*: "Like papers? But I mean how do you distinguish that?"*

In the case of another subject, when asked similar questions in relation to influential author and article:

Subject2: *"… I'd probably say perhaps the difference is that an author is a collection of influential articles…"*

From this example we can see that there are understandings and concepts arising that would have not been possible if it weren't for talking to the actual researchers. When all interviews have been fully analyzed, we expect to gain a better insight on what type of information users need when working with literature. Such information will assist in determining the entities that need to be represented and the desired relationships that need to be portrayed; hence this will assist in determining the application tasks. Tasks are the basis on which appropriate input devices can be chosen.

4.2. Validation Study: Usability of the LKD Tool

A LKD visualization tool will be developed based on the information gathered from the semi-structured interviews. A mouse-widget scheme will be used for interaction with the visualization tool at this stage. Usability studies are needed at this stage to ensure the validity of the tool. Such a study is considered a necessity due to the lack of a reasonably obvious and validated visualization design framework [11].

The aim of this study is to validate the usability of the visualization tool as a whole. Both the functionality and clarity of its metaphoric visual representation are to be validated. The study is intended to test whether the functionality of the interface meets the user requirements gathered from the interviews. In addition, it will assist in determining whether the visualization metaphor satisfies users' mental models.

Pre-test questionnaires will be given to subjects in order to capture their demographic information and their experiences using InfoVis systems. Subjects will then go through a brief practice session in which they will be trained on the system. Following they will then be given a list of tasks that are to be performed using the tool. The tasks will be divided into two major categories, domain-specific tasks, and visual representation tasks. Domain-specific tasks are intended to assess the functionality of the tool, in addition to determining whether the tool accurately portrays the information gathered from the interviews. The visualization-specific tasks will be generated from visual taxonomies as suggested by Morse et al [29]. The goal of such tasks is to asses whether users can understand the visual cues, such as color, clustering, size, etc.

During the study, subjects will be encouraged to describe their actions, observations and difficulties as they progress through the list of tasks. Subsequently, subjects will be given a questionnaire in which they will be asked to rate the usability of the system and the clarity of the visual representation (e.g. System Usability Scale (SUS) [7]). Finally a debriefing interview will be conducted; subjects will be asked questions related to their understanding of the system. Questions will include areas such as their rating of the functionality of the system, and its visual representations. Subject's suggestions will also be gathered.

Performance data collected from the study will be based on the number of correctly completed tasks. It is important to note that time needed for task completion will not be major factor in such a study. All problems encountered by users will also be collected. By analysing the data gathered from this study, modifications will be conducted on the tool. Depending on the results of the analysis and the type of required modifications, additional usability studies might be needed.

4.3. Mediated Device Selection

Devices differ in their structural and behavioural characteristics, which leads them to fall into different categories. However, it is important to note that even devices that fall into the same particular categories may be good for certain scenarios and not others. For example as Buxton [9] points out, a 3D joystick and a trackball are very similar in their characteristics. Yet, it is easier to pan with a trackball than it is with a joystick. However if the task involves panning and zooming simultaneously then a joystick would be the device of choice, this is due to the compatibility of the device's stimulus to the action required, hence the task.

At this point of the research, a clear set of tasks would have been determined, in addition to the dimensionality of the visualization tool. Therefore, task-specific devices can be determined at this stage. Several frameworks and taxonomies [1][5][10][25][27] are available which would assist in determining the device that would best suit the task at hand.

4.4. Experiential Study: Capture User Experience

A second prototype will be created. This prototype will be similar to the first except that the mouse-widget interaction scheme will be substituted by mediated interaction scheme in which task-specific devices will be used. Therefore, the two prototypes *will only differ in their interaction schemes and not the data's visual representations*. The first prototype will be referred to as the generic-tool, due to the generic nature of its interaction scheme, mouse-widget. The second prototype will be referred to as the mediated-tool, due to its mediated interaction scheme, task-specific devices.

The study intends to compare user experience when using the generic-tool versus the mediated-tool. Users' experiences will be measured by their ability to gain knowledge of the portrayed data. It will take the form of a co-operative evaluation, where subjects will interact with both the generic-tool and the mediated-tool.

A pre-test questionnaire will be given to capture subjects' demographic data, as in the previous study, in addition to their learning styles (how they perceive information), and experience using InfoVis tools and mediated input devices. A training session of both tools will follow. The subjects will then be presented with a list of tasks that are to be performed. Each tool will have a different set of tasks associated with it. The order in which the tools will be presented to the users will be randomized across users. Although the tasks associated with the tools will differ, it is important to note that they will have the same nature. All tasks will evaluate users' learning while interacting with the visualization. Bloom's [6] taxonomy will be used as a base for generating the tasks.

Bloom's taxonomy classifies intellectual learning behaviour as a linear progression through six levels, starting from the lowest, which is recall and comprehension of knowledge, to increasingly more complex and abstract mental levels, such as synthesis and evaluation. Due to the time restrictions, this study will concentrate on the lowest two levels, which are knowledge and comprehension.

In addition to the tasks, subjects' behaviours throughout their interaction with the tools will be videotaped since it is important to see whether the mediated interaction scheme will cause a change in their behaviours. Users will also be encouraged to think aloud while performing the tasks to describe actions, and difficulties. Post-test questionnaires (e.g. SUS [7]) will be given to the subjects to rate both the generic and mediated tools. A debriefing interview will follow to gather users' subjective experiences with both systems such as: engagement, pleasure and fun.

Collected data will include the following: performance data which would measure the correctness of the completed tasks, screen-video recordings which would capture task execution patterns, data logs which would include interface actions and examined nodes, and recorded behavioural observations. It is anticipated that the analyses of such data in addition to the personal data gathered from the pre-test questionnaire will give a clear indication whether or not such an interaction scheme would affect the visualization experience.

It is important to note that higher levels of learning will be difficult to capture during the experiment time. This is due to the fact that users would need more time and experience with the visualizations to be able to draw new knowledge and conclusions from the facts. Depending on time constraints, the subjects might be asked to interact with the systems for longer periods of time and report back on their experiences.

5. OUTCOME

In this paper we propose a different view of InfoVis. We stress that InfoVis is an *experience* in which users are cognitively engaged. Hence, every aspect that takes part in such an experience plays a major role in its augmentation. There are three major considerations that need to be taken into account when designing for experience: the user everyday experience in a context domain, the aesthetic aspects and the interactive aspects. Interaction is rarely considered as part of the current InfoVis systems, where most concern is related to the visual. But since visualization is not just about seeing, the other aspects of the experience should be taken into account.

The current understanding of direct manipulation in a mouse-widget interaction scheme is not the ideal solution when it comes to visualization experience, because users' cognitive flow breaks when interacting with the widgets. A proposed alternative to such an interaction scheme would be the use of a multiple specialized input devices that naturally fit the tasks at hand. We believe that such a setting would augment the experience. To test the validity of such a claim quantitative learning and behavioral data, and qualitative experiential data should be gathered and analyzed. We believe that such an alteration to the interaction scheme would affect the experience as a whole, and for really affecting the experience every little bit counts.

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