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Understanding the Role and Value of Interaction: First Steps

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Abstract

Visual Analytics strongly emphasizes the importance of interaction. However, until now, interaction is only sparingly treated as subject matter on its own. How and why interactivity is beneficial to gain insight and make decisions is mostly left in the dark. Due to this lack of initial direction, it seems important to make further attempts in facilitating a deeper understanding of the concept of interactivity. Therefore, different perspectives towards interactivity are discussed and cognitive theories and models are investigated. The main aim of this paper is to broaden the view on interaction and spark further discussion towards a sound theoretical grounding for the field.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Interfaces And Presentation (e.g., HCI)]: User Interfaces—Theory and methods

1. Introduction

The Visual Analytics (VA) community is consistently stating the value and importance of interaction for visual data analysis. Despite this, empirical studies or theoretical models that support these statements are scarce or missing at all. Until now the value of interaction has largely been treated as a minor issue in empirical studies. Nevertheless, it has mainly been promoted by experts as valuable asset. "Interactivity" and "interaction" are often used terms but concise definitions are hardly ever given. From the perspective of media, we might say that a paper map is static. But what if we cut and fold the paper map? Isn't that also interaction? And what if we use a paper map to find a certain street? We are obviously interacting with the world but where does the interactivity reside? In our tools? In us human beings? Albeit it sounds easy to define interactivity, the concept quickly becomes blurry. VA experts state that interactivity is a powerful concept that enables us to improve analytical reasoning in many ways. Studies like [SNLD06] also provide some evidence for this but research on describing *why* and *how* this is the case and the mechanisms behind it, is largely missing. As Liu et al. mention, *"the field still lacks supporting, encompassing theories"* [LNS08]. Therefore, they call for cognitive theories and models as the basis for research. This approach shall be picked up in this paper: First, we will discuss the concept of interactivity and its different facets. Second, cognitive theories and models will be investigated. The aim of this paper is to present different views on interaction and contribute to the research towards a *science of interaction*.

2. Related Work

In the research and development agenda for VA [TC05] it is claimed that current research too often focuses on the visual representation rather than on the interaction design. A *science of interaction* is called for that encompasses a systematic examination of the design space as well as a scientific theory and practice. Yi et al. analyzed prior research regarding interaction task taxonomies in [YKSJ07] and proposed a set of user intents guiding interaction. In [LNS08], Liu et al. examined the postcognitivist theory of Distributed Cognition and how it can be applied as theoretical framework for Information Visualization. A rudimentary human cognition model (HCM) is proposed in [GRF08] with the aim of achieving a better understanding of the coordination of human reasoning and interactive visual interfaces. Lam proposes a framework for interaction costs [Lam08] in analogy to Norman's execution-evaluation cycle [Nor88]. Pike et al. [PSCO09] aim to assess progress made since the original call for a science of interaction in [TC05] and define interaction challenges for the future. They report on the application of Situated Cognition and Distributed Cognition models. Recently, Liu and Stasko made an attempt to shed light on the relationship between internal and external representations and how interaction is related to these representations [LS10]. In this context, the role of interaction is mainly confined to external anchoring, information foraging, and cognitive offloading. Dou et al. assess the possibility and propose a framework for recording a user's reasoning process by capturing user interactions [DRC10]. Attempts to develop models for interaction have been made in related areas such as tabletop interfaces [SC06] or 3D interaction for Scientific Visualization [Kee10]. This paper aims to contribute to the research on interaction by broadening the theoretical basis to areas that have partly not been covered yet.

3. Interactivity

In order to be able to grasp the concept of interactivity, we follow the path of Stromer-Galley [Str04] who argues that we have to tackle interactivity from two perspectives – *interactivity-as-product* and *interactivity-as-process*. In the first view, interactivity is seen as a property of the medium itself, whereas in the second, interactivity is conceptualized as intangible concept of a process. These two views shall be used as starting points for further investigation.

3.1. Interactivity-as-Product

In the tradition of VA, interactivity is often seen as a property of the tool in terms of the elements offered for user interaction. According to Spence, *"[i]nteraction between human and computer is at the heart of modern information visualization and for a single overriding reason: the enormous benefit that can accrue from being able to change one's view of a corpus of data"* [Spe07]. However, while the benefits of being able to change one's view are often stated, there is hardly ever an explanation of what these benefits actually are as well as how and why they work. Of particular importance is the interaction style of *direct manipulation*. According to [HHN85], a major point of importance of direct manipulation is the fact that it gives a feeling of directness of manipulation. Reducing the information processing distance between the user's intentions and the facilities provided by the machine, makes the interface feel more direct by reducing the effort required by the user to accomplish goals. It is assumed that this feeling of directness results from the commitment to fewer cognitive resources [HHN85]. From a cognitive point of view, there are two main aspects of directness – *distance* and *engagement*. Norman [Nor88] describes two types of distances, which he termed *gulf of execution* and *gulf of evaluation*, which are part of his execution-evaluation cycle. Direct manipulation helps to bridge these gaps with less effort. *Engagement*, the second main aspect of direct manipulation, refers to *"a feeling of first-personness, of direct engagement with the objects that concern us"* [HHN85]. This provides a feeling of control that is generally perceived positively in contrast to communication with an intermediary. Interactivity is not simply a yes/no property of a tool or medium, but there are different degrees of interactivity which are determined by the extent to which a user can participate in modifying the visual representation [Ste92].

3.2. Interactivity-as-Process

Not the features of a tool or medium are the concern of interactivity-as-process, but the process of active discourse of users with the data. Therefore, also the user's tasks, goals as well as the interaction context are taken into consideration. The use of tools is deeply rooted in human development and even precedes the use of language [KN06]. Postcognitivist theories mainly follow this approach and focus on the process of interaction itself – activities of people using technology. In traditional HCI, the more narrow view of user-system interaction is taken. While this attempt is much richer with regard to including aspects related to users, the interactivity of artifacts themselves is not an issue. In this sense, also the process of visual perception can be considered as interaction with the environment. Visual perception itself is a dynamic process and does not work just like a digital camera. Quite on the contrary, visual perception is a highly dynamic process that is determined by many internal factors such as attention, focus, or experience [War04].

3.3. The Value of Interactivity?

Apart from investigating how interaction techniques work and how interactivity can be modeled, it is important to examine what users actually achieve by using interaction techniques [LNS08]. This is a question that is quite hard to answer. One possible explanation of the advantage of interactivity is, that it reduces the cognitive load by enhancing the expressiveness of the interface language (possible inputs and outputs) and minimizing the gulfs of execution and evaluation [HHN85] as already mentioned. Furthermore, externalization of information is beneficial. Norman argues that perceptual processing of external information is more efficient than processing internally represented information. Combining these two issues, interactive external representations can be handled with ease largely on a perceptual and physical manipulation level [Nor93]. Only recently, a small amount of studies has focused on the value of interactivity. A study on an interactive learning environment with varying degrees of interactivity shows that there is a greater preference for the interactive version [Ric06]. However, the study does not indicate that better learning had been achieved when interactivity was involved. In an insight-based study users preferred inferior visualizations with interaction over superior visualizations without interaction [SNLD06].

After investigating interactivity, cognitive theories and models will be assessed along their descriptive, evaluative, and generative abilities for interaction.

4. Cognitive Theories & Models

A central idea of cognitive science that emerged in the mid 1950s is that *"[t]hinking can best be understood in terms of representational structures in the mind and computational procedures that operate on these structures."* [Tha96]. Different approaches towards cognitive science were developed over the years: *formal logic* (inferences are made based on statements); *rules* (IF-THEN statements); *concepts* (frame application, cognitive scripts or frames that are getting parameterized and instantiated); *analogies* (case-based reasoning, adapting similar situations that are already familiar to us); *images* (picture-like mental representations); and *connections* (neural network of simple nodes and links).

Computer science and especially HCI draw upon cognitive science approaches to model the interaction between humans and computers in so-called *cognitive architectures* [Byr03]. Examples are Model Human Processor (MHP), GOMS (Goals, Operators, Methods, and Selection rules), Cognitive Complexity Theory (CCT), Collaborative Activation-based Production System (CAPS), Soar, LICAI/CoLiDeS, Executive Process Interactive Control (EPIC), and ACT-R 5.0. Almost all of the mentioned frameworks are production rule systems that build upon IF-THEN rules. *Model Human Processor (MHP)* [CNM83] provides a framework resulting from a synthesis of the literature on cognitive psychology and human performance up to that time. It describes a system that is composed of different types of memories and processors along with performance measures that are grounded on empirical studies. In MHP, the human mind is a specific type of an information processing unit, which has three subsystems: the sensory input subsystem, the central information processing subsystem, and the motor output subsystem. *GOMS (Goals, Operations, Methods, and Selection rules)* [CNM83] is an attempt to provide a framework for task analysis, which describes routine cognitive skills in terms of the four components – goals, operations, methods, and selection rules. It describes the hierarchical procedural knowledge a person must have to successfully complete a task.

The main points of criticism of the mentioned approaches are that neither physical nor social environments are recognized properly as cognitive science focuses on phenomena inside the head of a single human being. Therefore, so-called "postcognitivist theories" were developed that take these external factors into account.

4.1. Postcognitivist Theories

Artifacts are of special interest because computer tools can be seen as cognitive artifacts for external cognition that expand human capabilities [Nor93]. Their use not only affects the individual but also social interactions. The role of artifacts and social environments is emphasized in the theories like *Situated Action*, *Distributed Cognition*, and *Activity Theory*. Suchman [Suc87] challenged the assumption that human cognition can be modeled in a computer program and introduced a new theory of *Situated Action*. Here, human beings are seen as thinking through interaction with the world rather than by means of representing it and processing these representations internally – the individual's actions are influenced by the context of their specific situation. It builds upon the concept that the specific situation is the most important factor in determining what people will do.

Distributed Cognition largely originated from the work of Hutchins and colleagues [Hut96]. *"Cognition is said to be "distributed", meaning that it occurs not just in individual minds but through the cooperation of many individuals"* [Tha96]. People, tools, systems, etc. are all "media" and part of a system of nodes while human and nonhuman nodes are of the same type. Structures inside the human body as well as outside of it are part of the same cognitive system and treated equally. This means that knowledge is not only represented in the brains of individuals but also in the artifacts we are utilizing. Distributed Cognition also deals with the question of what transformations these structures undergo. In contrast to the Situated Action approach, Distributed Cognition emphasizes not the individual level but the cognitive system as a whole. A central tenet of Situated Action as well as Distributed Cognition is *embodiment* and *embodied interaction*. Dourish describes it as *"the creation, manipulation, and sharing of meaning through engaged interaction with artifacts"* [Dou01]. Another major element of Distributed Cognition is to understand the coordination among individuals and artifacts, that is, to understand how individual agents align and share within a distributed process. Thus, it is of particular interest when dealing with interactivity. This led to a first attempt to adopt Distributed Cognition as the underlying theory for interactive visualization in [LNS08].

Activity Theory distinguishes clearly between individual human beings and things. Moreover, a cornerstone of Activity Theory is that people deliberately commit certain acts by using certain technologies. This is at odds with the Distributed Cognition theory where both, people and artifacts are types of "media" in a system of nodes. However, Distributed Cognition takes both points of view throughout the work of [Hut96] – that of tool mediation and human performance which clearly separates humans and tools, as well as that of a cognitive system of like nodes. Activity Theory is an answer to both points of criticism of traditional cognitive science by including a rich social matrix of people and artifacts that grounds analysis. The unit of analysis in Activity Theory is an *activity* which is composed of *subject*, *object*, *actions*, and *operations*. The subject is a person or a group that is engaged in an activity. The object is the objective held by the subject. Actions are goal-oriented processes that must be carried out in order to fulfill the objective and actions might have operational aspects, which are low-level processes we are not aware of most of the time.

4.2. Summary & Discussion

A number of traditional cognitive science approaches as well as postcognitivist theories and models were presented in the last section. Activity Theory appears to be the most encompassing theory but also the most complex one. In terms of interactivity, traditional cognitive science focuses on user-system interaction and interaction itself is modeled mostly as simple input and output channels. Postcognitivist theories go beyond interaction between people and technology and account for the objects in the world with which subjects are interacting via technology in a social context.

5. Conclusion

The goal of this paper was to shed light on the concept of interactivity in the context of VA. Therefore, the central aspect of interactivity was tackled first from the point of view of research about interactivity itself and second, by investigating different cognitive theories. However, interactivity is not explicitly accounted for or modeled in these theories. Following the very definition of VA as *"the science of analytical reasoning facilitated by interactive visual interfaces"* [TC05] we can discern a focus on the aspect of interactivity-as-process in the first part of the definition. But the second part also hints towards the question of how the analytical reasoning can be supported via interaction concretely (interactivity-as-product). Putting it together, both perspectives, reflecting a top-down as well as a bottom-up view, are of particular importance and should be pursued in parallel. Another major aspect in VA is the intertwinedness of visual and automated analysis techniques that need to be integrated seamlessly. Special considerations are necessary to account for this also with regard to interaction. Apart from this, it is also important to take on a user's point of view and investigate how analysts see the role and value of interactivity. In a preliminary qualitative study we interviewed professionals in the business intelligence community. Surprisingly, we found that interactivity in visual methods is relatively unknown among users. However, interactivity is associated with supporting a deeper understanding of data for making well-informed decisions. Next, we plan the following concrete next steps: to investigate Activity Theory in cooperation with cognitive science specialists in depth for grounding interactivity from a theoretical point of view and to conduct empirical studies on how interactive features are used in which contexts and for which tasks as well as to investigate the effects of different degrees of interactivity.

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