Human-Computer Interaction and Cognitive Psychology in Visualization Education.

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Abstract

A curriculum designed to educate those who design, develop, and deploy scientific visualizations and/or visualization tools needs to contain a strong component of both human-computer interaction and human cognition. The argument centers around two observations. The first is the rapidly increasing breadth of application for computer-based visualizations and the tools for creating them. The second observation is that increasingly problems addressed using visualizations involve representing abstract objects, entities or relationships for which there is no obvious direct physical analog. Both trends point towards an increased need for understanding and incorporating visualization needs of an increasingly diverse set of users. In addition the trends towards increased diversity of users and the abstractness of representations being created for their use virtually demand an increased understanding of psychological nature of visualizations and their effects.
Keywords:*human-computer interaction, cognitive psychology, visualization education*

1. Introduction

Instances of scientific visualization currently range over many domains of human knowledge. For example, computer-based visualizations have been used to expand and contract time and space in ways that range from the modeling and rotation of entire galaxies to the enlargement and manipulation of models of molecular structure. Similarly, visualizations have made the invisible visible in ways that allow such things as viewing the dynamic movement of the valves the human heart and magnetic resonance imaging support for microsurgery. In addition, visualizations have made the difficult easy as in the case of software that graphs equations for calculus students or that enables a research mathematician to generate and manipulate complex surfaces as an aid to solving equations.

Currently, the ease with which computers track, record, and display information is leading to a flood of new uses of information visualization. Consequently, it is easy to envision even more diverse applications of computer-based visualizations in the near future as our knowledge of how to control the computer and visualization tools grows. For example, given that work is already taking place in these areas described below it is relatively safe to predict that in the next few years we will see an increasing use of and demand for information visualizations and tools for use in such application domain areas as:

1) Biomedical engineering of human health and performance through the creation of new devices for sensing and imaging of information which can be used in the design and development of new prostheses (e.g., stents to reinforce weak blood vessels, artificial limbs with improved functionalities, etc.) and new visualizations of complex patient data (e.g., combinations of vital signs and indicators being monitored on a patient in the hospital Intensive Care Unit.

2) Environmental science work engaging such diverse problems as automobile traffic control to reduce average trip time and auto-emissions; atmospheric or oceanic modeling of diffusion and chemical transformation of various pollutants; modeling the urban infrastructure to support planing and resource allocation.

3) The utilization of geoinformation systems in coping with such problems as geolocation and way-finding, public and private land use decisions, wildlife management, and police detection and control of patterns of criminal activity.

In addition, it is also easy to imagine that computer-based visualizations will play an increasingly larger role in future human use of information technology. The complex set of technological, environmental, and social problems facing the human race virtually demand that information technology (including computer-based visualizations) be used to support life-long career activities in knowledge workers from many domains. If correct, this prediction suggests that we also need to be concerned with the development of a wide range of strategies for reskilling and regeneration of professional careers. Many of these strategies for continuing professional education will, of necessity, come to depend more and more on the development of computer based visualizations which offer us new and fruitful representations with which to think about problems.

2. Why Human-Computer Interaction and Cognitive Psychology?

In all of the cases described above, visualization of the abstract will come to play an increasingly greater role. In other words, the problems to be addressed using visualizations will increasingly involve representing abstract objects, entities or relationships for which there is not an obvious direct physical analog [1]. Considering the wide range of technical subjects and knowledge areas which will contribute to the solutions of the types of problems described above, how are we to sort out which blocks of knowledge should be part of the education of developers of visualization tools and visualizations? Clearly such people will need to work in multi-disciplinary teams in order to call upon the contributions which can be made by specialists from other disciplines. Given all the technical material that a student of visualization will need to learn, and given the wide range of specialists with whom the student will eventually interact, why would anyone want to argue that human-computer interaction (HCI) and cognitive psychology are critical knowledge areas to be included in a curriculum for visualization education?

2.1. One Answer to the Question.

One simple answer to the question of "Why HCI and cognitive psychology?" is that there is already agreement about the importance of both topics to computer science education in general. For example, the report of the ACM/IEEE-CS Joint Curriculum Task Force [2] clearly identifies human-computer communication as one of the nine core areas of computer science. In this core topic the report authors include both computer graphics and human-computer interaction as related topics. Furthermore, the authors of the report point out that cognitive psychology is an important supporting discipline for three of the nine core areas of computer science, including artificial intelligence and human-computer communication.

2.2. More about HCI.

Beyond the fundamental natural affinity that exists between computer graphics and HCI, a more substantive argument for the importance of an HCI component to visualization education can be found in two simple observations. First, most computer-based visualizations or visualization tools are created with the intention of supporting some sort of human interaction with the visualization and the computer which creates it. Second, there is already in existence a reasonably clear delineation of the conceptual structure and knowledge modules which are central to the topic of HCI [3]. These resources have already proven useful in guiding the organization of major textbooks in HCI [e.g., 4] and continue to be of interest (e.g., during the last 12 months the report web site recorded over 9,000 hits, even though the report was published in 1992). Consequently, this existing catalog of knowledge modules makes it possible to explore and define the component aspects of HCI which should be considered part of an education in visualization technology.

2.3. More about Cognitive Psychology.

Substantive arguments for inclusion of the study of cognitive psychology in a curriculum on visualization derive from the fact that computer-based visualizations and tools are typically designed to make it possible for some sort of knowledge worker to achieve a set of work related goals. Typically, these goals involve developing the solution to a complex problem, or they involve the creation of new knowledge. Thus, designers and developers of computer-based visualizations and visualization tools need to be able to ground their designs in a knowledge of the end-user task or situation for which the visualization is being designed. Increasingly these visualizations and tools will require dealing with abstract relationships that are useful in enabling user's to think about their work.

As illustrated in [5], external cognitive representations can be powerful tools with which to think. Focusing on information visualization, Card, Mackinlay and Shneiderman [6] suggest six major ways in which visualizations can be used to amplify human cognition. Visualizations can increase the external memory and processing resources available to a user. They can reduce the user's need to search for information. They can enhance the user's ability to detect patterns in data or events. They can facilitate the drawing of some inferences through direct perception of the information rather than through more complex cognitive processing. They can facilitate the monitoring of change in large numbers of potential events. Finally, visualizations can be used to encode information in a manipulable medium.

The need to understand abstract relationships which the end-user is attempting to capture necessarily entails that the designer of a visualization, or of the tools needed to work with information visually, should be able to collaborate with the end-user in identifying the demands of the situation and in developing a knowledge representation appropriate to the way the end-user thinks, or needs to think, about the information being visualized. In other words, the designer has to develop an understanding of the problem being solved, why it is a problem in the first place, and what the constraints that determine an appropriate visualization.

However, for individuals educated only in computer science the problem of understanding the user's task oriented needs and goals can constitute a major barrier to development of appropriate tools, etc. For example, as pointed out in [7] and confirmed by the work of Harrison, Hewett and Perline [8], visualization of mathematics has some special features that require novel visualization techniques. Developers of many existing visualization packages have tended to view their task in a holistic manner which does not take these special needs into account. What has mattered from the perspective of the developers of existing visualization tools is the accuracy and speed of display of the whole model or scene. Consequently rendering is done in a buffer storage and is invisible to the user until completed. However, it turns out that in this case accuracy and speed aren't just irrelevant to many mathematicians, accuracy and speed may be completely contrary to the needs of mathematicians. For example, a visualization of the entire surface generated by an equation is not necessarily what is relevant to the mathematician exploring it. What matters even more is the evolution of the curve through another variable (e.g., time) that creates the surface. This necessitates a set of visualization tools and a visualization that can show the surface, the curves and the growth of those curves into the entire surface.

Another difficulty with traditional computer science education lies in the fact that our understanding of human behavior is, on the whole, limited to heuristic knowledge, whereas, computer science education typically deals with algorithms. Computer scientists are educated to deal with issues such as computability and completeness. Cognitive psychologists, because of the nature of their subject matter, are forced to spend much of their time working with heuristics, working with the conditionality of certain kinds of knowledge, and investigating knowledge representation. Indeed, a large measure of what has been learned in cognitive science in general is conditional knowledge which depends upon the circumstances in which information has been collected and which can only be characterized in the form of heuristics and conditional statements.

2.4. An Example of a Failure to Understand Cognition and Conditionality.

Although not based in an instance of scientific visualization, this example illustrates how a fundamental misconception about cognition might negatively impact the design of a visual representation of information. It also illustrates an important relationship between what has been referred to as knowledge in the head and knowledge in the world [5].

At a University which will forever remain nameless there are classes in which students are taught about HCI. In some classes, students are given the following design guideline: "The Macintosh interface is a bad interface because there are menus with more than seven items," the implication being, "Do not design interfaces such as that of the Macintosh." The logic of the argument, both explicit and implicit, runs roughly as follows. Miller [9] argued the capacity of short-term memory (STM) is 7 ± 2. Exceeding the capacity of short-term memory degrades recall performance. As noted, the Macintosh has menus with more than 7 items. Therefore, an interface such as the one found on the Macintosh will be a bad interface because the menus exceed the capacity of short-term memory and will lead to degraded human performance.

There are three problems that arise from applying this guideline to this design choice. First, menu items are generally related, e.g. File, Edit, Format, or View. That is, the contents of a menu tend to form a single chunk rather than a set of greater than 7 unrelated items. Second, menu titles are generally mnemonic and so provide effective recall cues for the items within. For both these reasons, menu titles aid rather than stress the user. Additionally, once the menu has been pulled down, the contained elements are visible and are now 'knowledge in the world [5].' None of the items must be stored in working memory. Using Miller's work to proscribe the design of GUIs with more than seven items per menu is misleading at best and is analogous to claiming that a coin has a bad interface because people have trouble recalling all of the information on its face [10].

Although presented in the particular, this example is not an isolated case. Several people have made this or a similar claim about the implications of Miller's work for human-computer interaction design. But what is important about this case is that it represents an attempt to get students to design from first principles. The reason that this is difficult stems from the nature of first principles and the resulting way in which they are stated. The statement "STM capacity = 7 ± 2" assumes but does not state the range of cases to which it applies. Nowhere, is it made explicit that items can be either atoms or chunks; and that capacity is only an issue when external memory aids are not present. The contextualizing information that tells the designer when Miller's work is appropriate is absent and so it is hard to use the abstract principle to either guide or constrain prescriptions for action.

In other words, the designers of visualizations and the tools which are used to shape them need grounding in the fundamentals of cognitive psychology in order to be able to adequately explore the user's task or situation for which the tool is being designed. They need to be able to identify and to deal with two types of psychological knowledge. One type of knowledge is that which will help the end-user solve the task related problem, i.e., the problem of designing an appropriate representation. The other type of psychological knowledge is that which enables the designer to understand the end-user's human cognitive performance strengths and limitations. It does little good and may even be harmful to create a visualization which does not map in some relatively natural and comfortable way to the cognitive structures of the end-user.

3. Concluding Remarks

In conclusion, designers and developers of tools and visualizations need to have a strong understanding of human-computer interaction and cognitive psychology. So long as it is easier to learn to write code than to learn to communicate with your life partner it will be easier to adopt and maintain a machine centered focus rather than a human-centered focus. Both knowledge of the user's cognitive performance limitations and knowledge of how to design representations which will contribute to the user's task relevant goals are essential to the successful creation of new tools or visualizations which will be both useful and usable in dealing with visualizations of abstract entities and relationships. An understanding of basic HCI and human cognition will help designers and developers to remain focused on the problems that should be solved rather than on the problems which can be solved. Solving a technically challenging implementation problem may produce the immediate gratification of having accomplished something, but it represents a trap if that solution does not simultaneously contribute to the end user’s task related goals.

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