HUMAN–INFORMATION INTERACTION: TECHNOLOGY AND THEORY

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Contents

Summary

Humans are distinguished by the extreme degree to which they have used technology to engage and adapt to their physical and social environments. Technology-boosted evolution is not without its tensions, since the amount of accessible information grows at an exponential rate, but unassisted human perceptual and cognitive capacities are fixed. This article presents recent advances in user interface technology and theory that aim to improve human interaction with globally distributed information. The field of information retrieval has produced techniques for automated search and organization of vast document collections. Novel information visualization techniques provide computer-supported, interactive, visual representations of abstract data that amplify human cognition. These novel user interface technologies reduce the cost-structure of interaction with information, allowing people to find more valuable information in reduced amounts of time. Information foraging theory is a broad psychological framework that aims to understand how people and technology are adaptive with respect to the cost-value structure of information in the environment. Information foraging theory provides a basis for developing quantitative and computational models that

predict the actual behavior of people when interacting with novel user interfaces connected to vast amounts of information.

1. Introduction

Cognitive psychologist G.A. Miller characterized humans as a species of *informavores*: curious creatures who gather and store information for its own sake, and who explore and use this wealth of information in order to better adapt to problems posed by the environment. Humans are distinguished by the extreme degree to which they have used technology to accelerate their evolution. This technology-boosted evolution is not without its tensions. Even though the amount of available information grows at an exponential rate, the unassisted human perceptual and cognitive capacities have probably not changed in any fundamental way since the beginning of the Upper Paleolithic era (40,000–50,000 BP). Technological advances that increase the volume and flow of information create pressures that must be met by technological advances that enhance our capacities for exploring, searching, and attending to that information (see *Advanced Geographic Information Systems*). This article presents user interface technologies and related theories that aim to improve human intelligence by increasing the capacity to find, process, and make sense of external information. The focus will be on the World Wide Web.

2. Emergence of the Global Information Ecology

The 1980s and 1990s witnessed an explosion in the amount of information that became available to the average computer user, and tremendous growth in new technologies for accessing and interacting with information. The processing capacity of computer memory chips has doubled every 18 months since Gordon Moore first observed the trend in 1965. Hard disk capacity grew 25% to 30% each year during the 1980s and has been growing by about 60% per year since 1991. The number of Internet hosts grew at an exponential rate from 188 sites in December of 1979 to 313 000 sites in October 1990 to 28 611 177 sites in March 2001. Whereas the average personal computer user of the early 1980s had access to perhaps dozens of files in local storage on an isolated machine, the average user of 2001 had access to about 525 billion documents on the World Wide Web (WWW). Currently, worldwide print and film content is growing at 2% and 4% per year respectively, optically stored content is growing at 70% per year, and magnetically stored content at 55% per year. The global per capita amount of unique content produced annually (print, film, magnetic, and optical) would require 2×10^9 bits of storage, and the total amount of unique content in the world doubles every two years. Much of the growth of the overall volume of information is contributed by sources—such as individuals with off-the-shelf consumer and office technology—that have not been associated with traditional media industries.

Computer access to stored information is far greater in developed nations than in developing nations. For instance, as of March 2000, there were an estimated 304 million Internet users, of which 137 million were in North America, 83 million in Europe, and 69 million in Asia and the Pacific. In contrast, there were 11 million users in South America, under 3 million in Africa, and under 2 million in the Middle East. This distribution in information access is roughly correlated with per capita income and wealth. For instance, the Internet penetration rates for citizens of developed nations such as the United States (42%), Canada (41%), the UK (26%), Germany (19%), Italy (16%), and France (15%) far surpasses that found in Latin America (less than 3%). One reasonable interpretation of these data would suggest that policies generally aimed at fostering economic development should help to diminish disparities in access to information technologies and access to content. It is notable, however, that direct investments in information technology appear to produce additional economic benefits.

Estimates by the US Federal Reserve suggest that 25% of the growth in GDP during the 1990s was due to information technologies. The Federal Reserve also found that industries that invested the heaviest in information technology showed the greatest productivity gains. This is in line with the expectation that improved information technology improves productivity by making markets work more efficiently, reducing transaction costs, and optimizing the allocation of resources. Future productivity gains from the Internet and computers are expected to be about 0.5% to 1.0% per year until at least 2011. Although this may seem small, the overall productivity growth for 1975 to 1995 was just 1.4% per year and just under 3% for the economic boom years of 1995 to1999. It appears that improved access to information technology creates more intelligent and efficient organizations, and it seems reasonable to expect that this effect should occur with individual users.

3. The Cost and the Psychological Structure of Gathering and Using Information

It is important to separate the costs and benefits associated with improved information technologies from those associated with just providing simple access to information. Nobel Laureate Herbert A. Simon observed that a wealth of information creates a poverty of attention and an increased need to efficiently allocate that attention. In an information-rich world, the real design problem to be solved is not so much how to collect and distribute more information, but rather, to increase the amount of relevant information gathered by a user as a function of the amount of time that the user invests in interacting with the system. If a user can attend to more valuable information per unit time, then the user's information processing capacity is increased, thereby amplifying cognition.

Environmental pressures produced by the ever-increasing availability of information have physical and emotional costs. Although worldwide content grows at the enormous rates indicated earlier, the unassisted human memory and cognitive processing systems are extremely limited. Estimates from a variety of studies suggest that unassisted human memory accumulates only about 10^9 bits of information (estimates range about one order of magnitude) at a rate of about 2 bits per second. There is a growing body of research suggesting that the great disparity between the volume, growth, and change of accessible information versus the human capacity to process that information has greatly increased stress-related behavioral and psychological problems in the workplace and home.

Most everyday tasks in the workplace and at home can be characterized as ill-defined problems. They are ill-defined because the goals, available courses of action, heuristics for measuring progress, and so on, are often unclear or under constant reformulation (unlike games or puzzles which have very well-defined goals and legal actions). Such ill-defined problems typically require substantial acquisition and integration of external knowledge in order to clarify the task and solution. Such tasks might include choosing a good graduate school, developing a financial plan for retirement, choosing a medical treatment, developing a successful business strategy, or writing an acceptable scientific paper. The structure of processing and the ultimate solution are, in large part, a reflection of the particular external knowledge used to structure the problem. Consequently, the value of the external information may ultimately be measured in the improvements to the outcomes of an embedding task.

The process of acquiring and using external information often involves several interleaved tasks. A person (or group or organization) typically has to forage for information, exploring sources and making decisions about what to pursue and process. The person has to make sense of the information, typically by coming up with some abstraction that synthesizes and simplifies raw information into a form of knowledge that is more easily manipulated. This knowledge is used to improve problem solving and decision making.

4. Intelligent Interfaces for Interaction with Information

Information access systems have measurable costs and value associated with their use (i.e., the amount of information that can be gained as a function of time). Design alternatives can be compared on the basis of these cost characteristics. User interfaces can place more information into the span of human attention by following the *principle of reducing the cost structure of information.*

The emergence of the global information ecology and, in particular, the WWW has created new challenges for the design of human–information interaction technologies (see *Interacting with GIS: From Paper Cartography to Virtual Environments).* The late 1980s witnessed several strands of human–computer interaction (HCI) research that were devoted to ameliorating problems of exploring and finding electronically stored information. It had become apparent that users could no longer remember the names of electronic files. The memory extender was based on a computational model of human associative memory and could automatically retrieve files represented by keywords that were similar to the sets of keywords representing the users' working context. Latent semantic analysis was developed to mimic human ability to detect deeper semantic associations among words, like "dog" and "cat," to similarly enhance information retrieval. Hypermedia gained wide spread use through the introduction of Hypercards by Apple Computer Inc. in 1987. Hypermedia techniques date back to Vannevar Bush's *Atlantic Monthly* article "As We May Think" published in 1945, but it was not until the confluence of increased computing power, storage, and networking in the late 1980s that the stage was set for hypermedia in the form of the WWW in 1990.

Interaction with the WWW typically involves a user interacting with a browser that communicates with one or more servers that find and deliver information from various repositories (see Figure 1). Interaction can be improved by improving the backend technology that delivers valuable information at an improved rate, or by improving the user interface to that technology. The current state of interaction with the WWW is rather dismal if measured by the success with which people can accomplish simple tasks. For instance, it is estimated that 65% of virtual shopping trips on the web end up in failure, 40% of site visitors do not return because of problems, and WWW site redesigns aimed at ameliorating such problems were estimated to cost US$1.5 million to US$2.1 million in 1999.

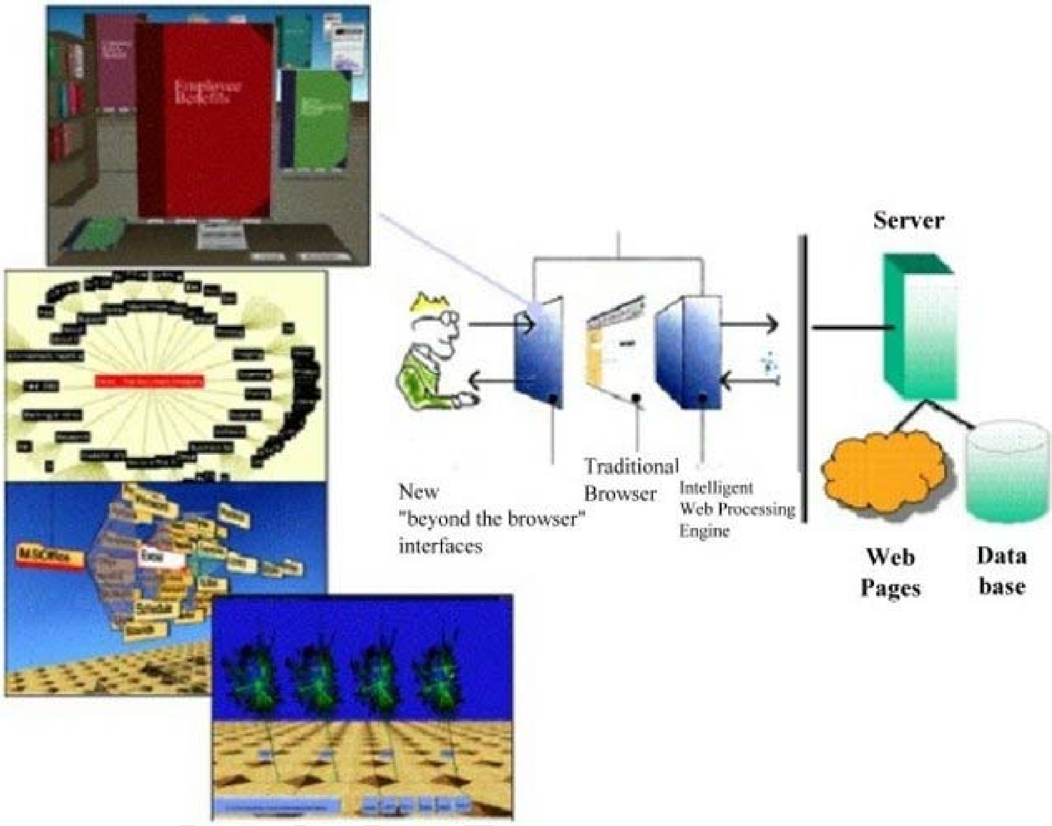

Figure 1. An overview of user interaction with the World Wide Web (courtesy of S.K. Card)

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Bibliography

Card S.K., Mackinlay J.D., and Schneiderman B. (1999). *Information Visualization: Using Vision to Think*. San Francisco: Morgan Kaufmann. [This edited volume contains most of the seminal papers in the field of information visualization as well as an organized overview of the field.]

Lyman P., Varian H.R., Dunn J., Strygin A., and Swearingen K. (2001). *How Much Information?* Online: <http://www.sims.berkeley.edu/research/projects/how-much-info/> [This WWW site is an attempt to measure the amount of information produced in the world.]

Pirolli P. (1999). Cognitive engineering models and cognitive architectures in human-computer interaction. *Handbook of Applied Cognition* (ed F.T. Durso, R.S. Nickerson, R.W. Schvaneveldt, S.T. Dumais, D.S. Lindsay, and M.T.H. Chi), pp. 441-477. West Sussex, England: John Wiley. [This handbook chapter provides a introduction to computational models of human computer interaction.]

Pirolli P., and Card S.K. (1999). Information foraging. *Psychological Review*, 106, 643–675. [This paper presents a detailed mathematical and computational theory to address how people find and explore information.]

Biographical Sketch

Peter Pirolli is a Principal Scientist in the User Interface Research Area at Xerox PARC. He received his B.Sc. in Psychology and Anthropology from Trent University, Canada, where he conducted and published research related to eyewitness memory. He earned his M.S. and Ph.D. in Cognitive Psychology from Carnegie Mellon University where he developed computational models of students learning to program and helped develop an intelligent tutoring system for programming. He became a Professor in the School of Education at the University of California, Berkeley, where he was also Associate Director of the Cognitive Science Program. During that period he studied computational models of metacognition, intelligent tutoring systems, and design problem solving, and he became a Fellow of the National Academy of Education. He joined Xerox PARC in 1991 where he is engaged in studies of human–information interaction, information foraging theory, and the development of new user interface technologies.