Design of Interfaces for Information Seeking
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INTRODUCTION AND PERSPECTIVE

Understanding the information-seeking process and developing systems and strategies for supporting it are central goals of information science. Research in the organization and communication of information is best informed by studies of the interactions among people and external information sources. However, information technology has advanced so rapidly in the second half of the twentieth century that it dominates research and development in information seeking, and the linchpin of this interactivity is the user interface. The interactions among human physical, cognitive, and affective subsystems and the external world are defined by the juxtaposed boundaries where these physical and conceptual constructs meet. Such conjunctions of boundaries are called interfaces. Interfaces serve as the communication channels through which information seeking proceeds. Defining and building interfaces that support information seeking is thus a fundamental problem in information science and there is a rich history of work that may be found in the human factors and human computer interaction (HCI) literatures as well as in the information science literature.

The centrality of user interface design to information science is reflected by the inclusion of chapters on the topic in four of the first eight volumes of ARIST (DAVIS; LICKLIDER; BENNET; MARTIN). Four subsequent volumes devoted chapters to different aspects of user interface design. The most recent chapter, by SHAW in 1991 noted the rapid developments in the field and importance of user interfaces to information science progress. This chapter aims to provide a link to the earlier work while focusing on the current state of user interface design for information seeking. The goals of this chapter are to frame the evolution of interfaces for information seeking, provide a status report for current research and development, and suggest research directions. The fields of HCI and human factors are broad and rich and we focus on interface designs that support information seeking. Likewise, there is a considerable body of work related to interfaces for information systems (e.g., text processing, graphics, programming, etc.) within the information science literature that is not considered here. The field of Computer Supported Collaborative Work was an offshoot of HCI and the reader is referred to the TWIDDLE chapter of this volume for the social aspects of interfaces and human-computer interaction. Within the research and development devoted to interfaces for information seeking, we focus specifically on conceptual interfaces and give only broad coverage to physical interfaces. The chapter is organized to first provide a perspective on the mutually dependent advances of technology, information seeking research, and human-system interaction; provide a brief summary of developments in the first two generations that have been addressed in previous ARIST chapters; and then focus on the current generation of development considered from multidisciplinary and interactivity perspectives.

Technology Push and Interdisciplinarity

There can be little doubt that in the last third of this century the workplace has been transformed by information technology. The impact of technology on information processing is nicely summed up (TALBERT) by WULF's appeal to Moore's law as the driving force for engineering innovation: "Anything that is changing at that rate just can't be ignored." The rapid evolution of technical development is reflected in hardware and software, in the user interfaces that link people to systems, and in the information industry that supports information-seeking activities. Because information technology strongly determines the ways that people interact with information, there are inherent commonalties in information science and the emerging field of human-computer interaction. The influence of technology in pushing research and development in information seeking and interface design is summarized in Figure 1. Three generations of technology, roughly mapped onto the final three decades of the twentieth century (the first generation also includes much of the 1960's), have had strong influences on what new information products and services were created and how human interactions with information evolved. Figure 1 provides a perspective on how information seeking research and interface design research developed in parallel, both driven by technological developments. This perspective serves as a framework for this chapter.

Information seeking research takes into account users, tasks and knowledge domains, information systems, and contexts, and the changes in the research and development focus of these elements are highlighted as systems evolved. Attention to users grew from highly specialized professionals who were trained to use

Figure 1. Three Generations of Technology-Driven Information Seeking and Interface Design Research and Development.

	Technology R & D	**Information Seeking R & D**	**Interface Design R & D**
1970's	Mainframe Custom Programs File management	Users: professional intermediaries Context: workplace Content: pointers Tasks: single, batch-oriented Interactivity: Structure: fielded files Rules: discrete, sequential	Users: programmers/experts Context: workplace Content: ASCII characters Tasks: specialized, iterative Interactivity: I/O: dumb terminal Style: command line/menu
1980's	Personal Computers Application Packages DBMS, Adv. IR	Users: literate end users Context: workplace/home/public Content: full text Tasks: multiple, sequential Interactivity: Structure: relational, hierarchical Rules: iteration	Users: literate end users Context: workplace/home Content: graphical Tasks: multiple, coordinated Interactivity: I/O: GUI/WIMP Style: direct manipulation
1990's	Distributed Systems WWW Hypermedia, Adv. IR+browsing	Users: universal Access Context: ubiquitous Content: multimedia Tasks: integrated Interactivity: Structure: network objects Rules: customizable, parallel	Users: universal Access Context: ubiquitous Content: multimedia Tasks: integrated, distributed Interactivity: I/O: multiple Style: enhanced direct manipulation

movement from character-based to multimedia-based interfaces, a similar progression of more integral subtasks, development of new, specialized physical interface devices for input and output, and a progression of interaction styles from batch-oriented command styles to directly manipulable visualizations. This framework highlights the parallel development of information seeking and interface design research--both mutually dependent on technology developments--and illustrates the many interdisciplinary overlaps.

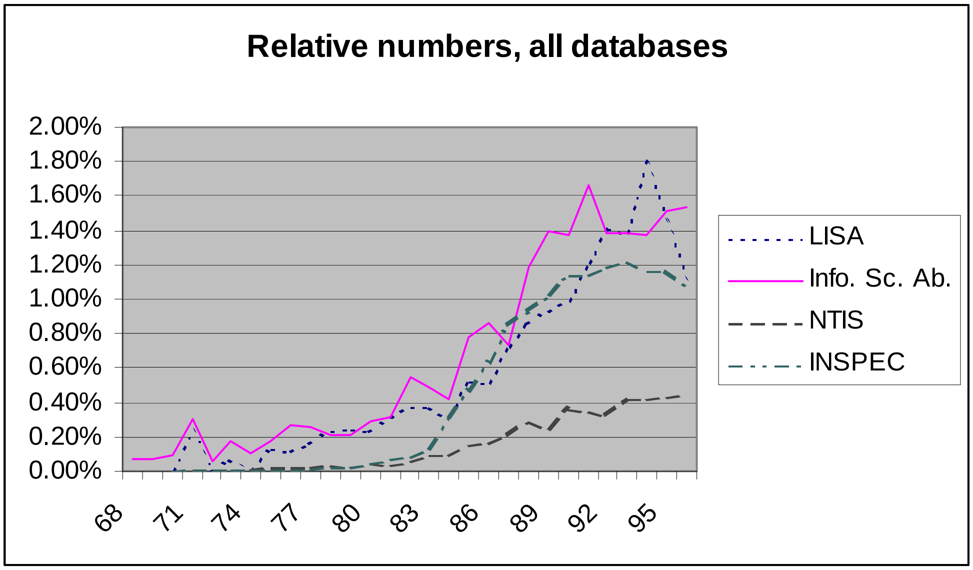
Literature Trends

The importance of interface design is reflected in the research literature. Over the past thirty years, many new journals devoted to HCI have appeared, there has been enormous growth in conferences devoted to HCI research, and specialized funding programs have been developed by government agencies and foundations. We conducted literature searches to follow the user interface literature both in information and library science and computer science. The searches were carried out in four databases through the Dialog service: Library and Information Science Abstracts (LISA), Information Science Abstracts, National Technical Information Service (NTIS) and INSPEC (The Database for Physics, Electronics and Computing). The first two databases cover the library and information science literature. Both databases have international coverage and contain bibliographic data and abstracts. LISA contains records from over 500 journals and other publications from 60 countries, including information about ongoing or recently completed research. Information Science Abstracts monitors over 300 journals, as well as books, conference proceedings, research reports and patents. INSPEC covers the international computers and control and information technology literature among other topics. NTIS is the source of information for government-sponsored U.S. and worldwide scientific, technical, engineering, and business-related information.

INSPEC was the largest among the databases (5 million records in July 1997), although both CS databases were significantly larger than the library and information science ones, since their subject coverage was much larger. NTIS had 500,000 unrestricted technical reports, Information Science Abstracts contained 165,000 citations, while LISA had 130,000 in July 1997.

The same search for the phrase "user interface" was conducted in all four databases limiting the results by year between 1968 and 1997. The data from 1997 was not included since the literature had not been fully indexed by the time of the searches. The results are presented in Figure 2 by the ratio of hits to the total number of records from that year in the database. In all four databases three phases can be observed: from the end of the 1960s until the beginning of the 1980s the literature was very small and very slowly increasing. Between 1980 and 1990 the amount of user interface literature increased rapidly, leveling off in the early 1990s. These trends can be seen in all four databases. The absolute number of records shows this trend even more dramatically.

Figure 2. Literature search on "user interface". Ratio of number of hits to total number of records in database 1968-1996.



An additional search was conducted in the Association for Computing Machinery Digital Library that at the time of the searches contained 95% of all ACM journals and proceedings from 1991 in full text and the bibliographic data of all ACM journal articles from 1985 on. This search showed similar overall trends, although a more erratic graph due to the much smaller base of records. The number of papers with user interface in the text increased steadily, showed a big drop in 1994, but then returned to the previous level in 1995 and then dropped slightly in 1996.

We speculate that the leveling off about the 1994 period are due to the rise of the WWW, which captured the attention of researchers in technical areas and in its earliest forms strongly affected user interface design by eliminating the basic design paradigms (e.g., multiple windows), interaction models (e.g. statefulness), and widgets (e.g., sliders).

User Centered Interface Design

The field of human-computer interaction has developed as a confluence of people and work in psychology (the human factors community), computer science, and information science. In an early ARIST review of “man-computer communication” LICKLIDER devotes the bulk of his chapter to hardware developments, especially the time-sharing breakthroughs of that time and bemoans the Tower of Babel of programming languages and lack of attention to human intelligence instead of artificial intelligence. Only five years later, BENNETT in his ARIST review of the “user interface in interactive systems” was able to discuss basic interaction metrics (response time and ease of use) and include results from several empirical studies of users other than programmers using a variety of retrieval systems. Bennett focused on the nature of interactivity by identifying four components of interactive systems and giving examples of how they interact in some early online environments such as INTREX (MARCUS ET AL.) and Dialog (SUMMIT). These four components of interactive systems; task, user, terminal, and content, draw upon progress in many disciplines and remain central today, although most researchers would add a context component (e.g., NARDI). This interdisciplinary approach to interactivity is fundamental to both human computer interaction and information science and inextricably binds them in a self-reinforcing manner.

Good histories of the HCI field may be found in a chapter by BAECKER ET AL., and a recent paper by SHACKEL (1997). Four pioneers must be noted here as they defined four themes--interaction, human augmentation, usability, and multimedia--that resonate in the interface design community today. These early visionaries in the computing field recognized that people are central to practical computing systems and established the primary challenges of interface design. LICKLIDER was concerned with the symbiotic relationship between humans and computers—the nature of interactivity, envisioned digital libraries used by ordinary citizens, and argued for designers to consider user needs throughout the design process. ENGLEBART articulated the vision that computing could be used to augment the human intellect and demonstrated his phronetic genius by leading design teams that created new devices (mouse) and interactive tools (collaborative authoring and hypertext systems) that underlie human-machine interactions today. SHACKEL (1959) launched the European tradition of usability testing based on ergonomic factors, and SUTHERLAND (a, b) demonstrated the potential of graphical displays with his Sketchpad system and the original head-mounted display. These early pioneers put their theories into practice through prototypes and working systems and inspired a generation of scientists and innovators by insisting that humans and their tasks must be central when information technology is designed.

User interface designs take into account users, tasks, and technology and develop according to a user-centered design process guided by empirically determined principles and guidelines, and informed over multiple iterations by usability testing. The main advances in design process have come from psychology-based studies that focus on human behavior. NORMAN provides cogent examples of how people take cues from the environment during interactions and contributes a framework for user interaction in which user goals drive execution (intention, action sequence, and physical sequence) and evaluation (perception, interpretation, comparison) cycles. This framework is especially applicable to the design of user interfaces that support iterative search that depends on intermediate results. More specific to user queries, LANDAUER’s group conducted many empirical studies of how people name concepts. For example, DUMAIS & LANDAUER summarize experiments that illustrate that novices formulate rather simple queries and discuss the interactions between popularity of terms in command languages and the specificity users need when doing their individual tasks. Subsequent work (e.g., GOMEZ ET AL.) demonstrates the need for rich indexing if query interfaces are to support user natural language queries.

There is a long history of task analysis research that informs interface design. There are two primary approaches to identifying user needs and building principles for design. The cognitive engineering approach is best illustrated by CARD ET AL. (1983), who developed the GOMS (Goals, Operators, Methods, and Selection rules) model for user interaction as a formal theory upon which precise user performance could be predicted. The basic model grew out of many carefully controlled text-editing experiments and was the first formal model of human-computer interaction. The original GOMS model depends on error-free, sequential user behavior and does not take into account user learning as the task progresses, however, many researchers have created adaptations that address some of these strong constraints. JOHN and KIERAS, who have both independently applied GOMS-like models in complex interface design work, provide an excellent summary of the various GOMS models (JOHN & KIERAS 1996a, 1996b) and an empirical comparison of four models applied to the task of paragraph editing embedded in a larger collaborative writing task.

An alternative to the cognitive engineering approach is more holistic and considers the user and task as situated in a larger milieu. This approach is best illustrated by the work of CARROLL and his colleagues who advocate phased designs appropriate to users’ varying needs. In a seminal chapter, CARROLL & ROSSON (1987) define the “paradox of the active user” arising out of peoples’ needs to get their work done rather than learn new systems and peoples’ tendencies to learn new systems through analogy. They stress that these are not human flaws in human learning that designers should aim to remedy but important properties upon which user-centered design should be based. From this perspective, they propose “training wheels" designs that are extensible, use progressive disclosure of features as users gain experience, provide undo features and guided explorations, and minimize dependency on metaphors that constrain learning of new features. This holistic approach to users and tasks also gives rise to scenario-based design and user testing (CARROLL & ROSSON, 1992).

Another aspect of interface design that gets broad attention in the research literature is the specification of the design process itself. The importance of planning, testing, and team work in software engineering is demonstrated in the classic essays of BROOKS and such experiences in building large-scale systems influenced recognition of the need for interface design. SHNEIDERMAN (1998) has articulated a design model that integrates psychological research, computer science principles, and technical tools as the basis for fifteen years of interface designs in his laboratory. This model is based on theories and models of HCI and empirical research and aims to incorporate iterative usability testing, user interface management systems, and guideline documents to develop successful designs. NIELSEN has produced a practical volume on usability testing, and HIX & HARTSON present a practical guide to the user-centered design process.

Information Seeking in Electronic Environments

Information seeking is a process in which humans engage to purposefully change their state of knowledge. The process is inherently interactive as information seekers direct attention, accept and adapt to stimuli, reflect on progress, and evaluate the efficacy of continuation. Information seeking is thus a cybernetic process in which knowledge state is changed through inputs, purposive outputs, and feedback. Information seeking is, however, a strictly human process that requires adaptive and reflective control over the afferent and efferent actions of the information seeker. We distinguish information seeking from information retrieval in that information retrieval does not demand persistence or continuous human attention, that is, retrieval may aim to yield an intermediate value that is applied and then forgotten, also, information retrieval may be automated and embedded in the larger information-seeking process. Progress during an information seeking episode is thus a product of information seeker attributes, informational environment attributes, and the communication channel over which information flows.

There is a rich literature related to information seeking, including numerous ARIST chapters on user needs. We provide a terse summary of key work leading to the current focus on human interaction with analog and digital information. Early studies of information-seeking behavior demonstrated that users progress through different stages as they recognize, and articulate an information need. TAYLOR's classic four stages (visceral, conscious, formalized, and compromised) illustrate the long-standing research focus on question articulation, and DERVIN helped the field focus more on the communication of needs as the essential aspect of information seeking. BELKIN (1980) focused attention on the information seeker's initial state of mind by proposing his anomalous state of knowledge framework and then moved beyond theory to apply the framework as a basis for system design. BATES (1979a, 1979b) created a taxonomy of practical strategies and tactics that information seekers could use during search and, which also served as the basis for interface designs. Work by BATES (1989), MARCHIONINI (1995) and others added empirical legitimacy to systems that support and depend on user browsing strategies. BORGMAN (1984) explained user information-seeking behavior by examining users' mental models for the retrieval system and knowledge domain, and KULTHAU (1988) extended the model of information seeking as a cognitive process by adding an affective dimension.

SARACEVIC has recently summarized the current view of information seeking as an interaction between people and information. Based on models developed by BELKIN (1996) and INGWERSEN, this view integrates factors and processes where the interface connects resources (both informational and computational) and the user (user characteristics, user query, and environment) at different temporal (as interaction progresses) and conceptual (surface/behavioral, cognitive, and situational) levels. Thus, information-seeking research currently rests on the foundational work done with users and information systems and focuses on the nature of interactions with information.

In many respects, this evolution in information seeking research has been driven by technological developments that explicate the information-seeking process by dramatically speeding up the pace of iterations and broadening the scope of access. MARCHIONINI (1992, 1995), adopting this view of information seeking as a dynamic, interactive process, pointed out that most system and interface designs focus on the query aspects of the larger information-seeking process and argued that designers take a more integral view when designing user interfaces. As Figure 1 suggests and the sections that follow demonstrate, the research paths for information seeking and user interface design reflect parallel evolutions as the fundamental phenomenon—interactivity—is addressed at more holistic levels with frameworks that combine the respective factors and subprocesses of these mutually reinforcing fields.

FIRST AND SECOND GENERATION USER INTERFACES

The computer systems augmenting information seeking in the 1960s to the 1980s evolved from batch-oriented systems with machine-centric interfaces (programming) to interactive systems with novice-user, graphical user interfaces. This progress was driven by advances in hardware (from large mainframes to personal computers), architecture (from time-sharing to client-server), software (from customized programs to general applications packages), data structures (from file management to database management) and interfaces (from character-based interfaces to graphical user interfaces). The early systems supported only analytical search strategies for well-defined, text-based bibliographic information and thus were required considerable sophistication to use. Over the two generations, there was an unmistakable trend toward supporting broader communities of users, richer information objects, and more interactive search strategies, culminating in late 1980s with graphical interface designs to browsing in hypertext environments. Two main types of applications most clearly illustrate these trends in information seeking interfaces: online information retrieval from databases, and online public access catalogs (OPACs). The interfaces for these types of systems typically allowed users to retrieve information from a specific database or collection and mainly supported query formulation.

Online Information Retrieval System Interfaces

The first systems allowing remote searching of databases were developed in the late 1960s as time-sharing became viable. The first services were batch searches run on data stored on tapes. In the early 1970s GECHMAN reported a movement towards interactive searching and predicted development in more refined search capabilities. An excellent volume stemming from a 1971 American Federation of Information Processing Societies (AFIPS) workshop focused on interactive searching illustrates the early interest in interfaces for interaction (WALKER). This volume includes papers about the pioneering systems of the period such as NASA/RECON, the precursor to Dialog, AIM/TWX, the precursor to Medline databases and the Grateful Med interface, and other novel systems that served as foundations for other commercial or research systems (e.g., BASIS-70 and Intrex). A key unifying theme was in techniques to support interactive information retrieval by users working at terminals remotely connected to systems in real time. By 1974, interactive, online searching had become common and WILLIAMS, M.E., in her ARIST chapter examined software for database searching and reviewed both batch and online database searching software, some of which included user aids such as an online thesaurus.

The 1970s saw continued development of robust commercial services for online retrieval and the continued evolution of experimental systems. HAWKINS reviews the history of these services until 1981, including interface aspects. He comments that most online searches require an intermediary because of the complexity of the interfaces and the differences between systems. Intermediated searching was typical of the 1970s, although several authors cited in the chapter predict the growth of end user searching. HAWKINS treats the evaluation of searches and searchers, the reference interview and search strategy formulation as part of the user-side interface, what we consider part of the conceptual interface.

The first intermediary interfaces automated the logon procedures, the selection of files and systems and other housekeeping tasks. Experimental systems went far beyond this to support user query formulation. The NLM CITE (DOSZKOCS) system was one of the first interfaces to provide search support by allowing natural language input of search entries. The system picked out the search terms from the queries and carried out a weighted search of the terms. The system also allowed relevance feedback and query modification. The interface was menu driven rather than command based, showing a trend towards easier dialog methods to support end users. A different theme of development built upon artificial intelligence techniques to automate the intermediation process. KEHOE traces the history of the INTREX research project at MIT, one of the first initiatives to automate intermediation and led to the CONIT, later IIDA interfaces and the Sci-Mate (SAARI & FOSTER) front-end in the 1980s. The 1970's saw the development of commercially viable systems that provided basic support for professional intermediaries to execute sophisticated queries and experimental systems that aimed to support broader user communities.

Just as the 1980s saw the spread of personal computers, information-seeking system interface research and development focused on end users. This trend started with the emergence of online public access catalogs that provided end user access to bibliographic data of library's holdings. Online information services started to supply gateway or front-end software to support this new user group. MISCHO & LEE define gateway software as packages that take care of housekeeping tasks such as logging onto a database. Front-end interfaces aim to make the search transparent for the user by taking care of some of the search steps such as database selection, translation of query into the syntax of the database. MEADOW ET AL. presented front-end research and early work on user needs and professional search strategies, culminating in the OAK interface. Commercial database vendors started to provide front-ends; DIALOG's In-Search (NEWLIN) and BRS's After Dark (JANKE) were good examples. These interfaces supported the end user better and tried to provide the expertise of the intermediaries in the interface.

More powerful computational platforms of the 1980s also allowed designers to build interfaces for systems that used advanced information retrieval techniques that supported non-Boolean queries and returned ranked results. The OKAPI text retrieval system developed through a series of research projects (ROBERTSON) focusing on user information seeking behavior, user-system interaction and systems design. The OKAPI systems are designed for non-expert end users. The search queries are entered in free text form and then parsed into word-stems. The system searches based on a best-match function with term weights and produces a ranked list of documents. The user can provide relevance feedback based on these results and perform a relevance feedback search. The search process can be iterated through several cycles. Different variations on these options were implemented and tested.

VICKERY and VICKERY reviewed many of the interfaces developed for online systems organized around different steps of the process of searching online bibliographic databases. They list thirteen steps in the online search process and discuss twelve functional requirements for online interfaces. This in-depth analysis begins with a user who already has a query and does not address the extraction and use of information found in the search. Thus, their extensive bibliography on the topic reflects the IR field's focus on query formulation, reformulation, and results inspection.

Online Public Access Catalog Interfaces

The 1980s delimit the era of the Online Public Access Catalogs (OPACs), which emerged as extensions of library circulation systems or as separate tools developed to provide user access to bibliographic information. VIGIL makes a distinction between online information services and OPACs. The difference lies in the search language: online systems supported sophisticated queries and allowed users to combine sets and reuse results of previous queries, while OPACs aimed at allowing novice users to enter only the most basic queries. OPACs were also more suited for known-item searches and less for subject searches that were better supported by online databases. User studies of OPACs found that users have more difficulty with subject searching (BORGMAN 1986)

HILDRETH in his 1985 ARIST chapter reviews the history of OPAC interfaces. The first public access systems appeared in the late 1970s with limited functionality. The real spur of OPACs started after 1980 when many libraries started to develop their OPAC interfaces or urged the commercial library automation system vendors to develop OPAC subsystems. The emphasis in these systems was on public access. The first large-scale OPAC studies were conducted in the early 1980s (HILDRETH ET AL.). User studies found the OPACs were very popular among users despite the difficulties of use that occurred.

HILDRETH defined three generations of OPACs in 1983 based on search/access, interaction/dialogue mode, display format/content, and operational assistance. The three generations show development from restricted known-item searches to subject searching, more powerful search capabilities, and interactive search refinement. The searching capability developed from character-by-character matching similar to card catalog use to Boolean searching, keyword access and other more flexible searching methods. The interfaces progress from command-driven to multiple dialog modes offering both menu-driven interfaces for novice users and command-based dialogs for expert users. Hildreth predicted that future third-generation OPACs would include powerful search capabilities and intuitive user interfaces that provide point-of-need help and instructions.

BORGMAN (1986) summarizes findings from information retrieval user studies and concludes that users of online information retrieval systems and OPACs experience similar problems when searching. She defines two types of knowledge used in searching: knowledge of the mechanical and the conceptual aspects of searching. Later (1996) she refines this model to include semantic knowledge of how to implement a query in a given system. In her 1986 article she summarizes problems users have with the mechanical and the conceptual aspects of searching and identifies sources of problems. In her 1996 article she states that OPACs are still hard to use. She suggests that human factors knowledge should be applied to information retrieval screen design and identifies further research areas such as standardization of command languages and screen displays, error correction algorithms, and the development of front-end or "automated intermediary" systems.

The later years of the 1980s and early 1990’s showed several OPAC interface development efforts. Children were studied as information seekers and OPAC interfaces were designed to suit their needs. BORGMAN ET AL. (1995) summarize related research and describe studies conducted on the Science Library Catalog Project. This system provides a Dewey Decimal Classification-based graphical browsing interface that allows hierarchical browsing without the use of a keyboard. BUSEY & DOERR describe another interface designed for children, the Kid's Catalog. This interface incorporates ideas from the Science Library Project and user studies of children's information seeking behavior. It provides multiple access points to the materials to accommodate different developmental stages. BookHaus (PEJTERSEN) is another effort to design a graphical OPAC interface. This system is especially interesting because, like a physical library interface, it provides alternative conceptual interfaces for users and tasks. For example, the children’s collection and search service is distinguished from adult fiction and non-fiction interfaces. The ACCESS system at the Library of Congress provides a touch panel direct manipulation interface with context-sensitive hypertext help (MARCHIONINI ET AL., 1993). HYPERCATalog developed at LIBLAB in Sweden (HJERPPE) applies hypertext links across related objects in the OPAC interface.

More recent OPACs continue to leverage GUI-based techniques and advanced information retrieval techniques. BEHSHTI ET AL. (1996) describe the PACE (Public Access Catalog Extension) interface. This system provides a graphical browsing interface simulating images of books and library shelves to help users browse through the catalog. User testing showed that the graphical browsing display provided the same user performance as the character-based display, but users overwhelmingly preferred the graphical browsing display. Just as experimental online search systems were implemented in practical settings, the ongoing work on the CHESHIRE system (LARSON) is the basis for working OPACs while continuing to serve as an experimental platform for OPAC research. Cheshire aims to incorporate advanced IR and interface research to provide a GUI interface to multimedia objects using a Z39.50-compliant architecture that leverages both SGML markup and a probabilistic retrieval engine.

Clearly, there were astounding advances in information-seeking capabilities over these first two technological generations. This summary only highlights two application areas and ignores studies of intermediary and reference interviews, searching behavior, user modeling techniques, search engine functionalities, and other related areas of research that influence user interfaces. However, this discussion illustrated the trend toward highly interactive interfaces that provide universal and ubiquitous access to a variety of information objects.

THIRD GENERATION USER INTERFACES

The current generation of research and development in user interfaces that support information seeking is mainly influenced by ongoing technical developments that give more computational and communicational power per unit cost, practical portable devices, funding for digital library research, and especially the development of the World Wide Web. These developments are leading to a global information economy in which all the world's citizens will depend on access to electronic resources.

Users

As computers and telecommunications costs drop, larger portions of the population take advantage of information technology. Today, the WWW links people of all ages and backgrounds around the globe. In the interest of global cooperation and to expand the information technology marketplace, there is a growing call for universal access to electronic information resources. The WWW has accelerated efforts to develop multilingual interfaces, which improve as underlying research in machine translation and multilingual text retrieval progresses. Some systems retrieve documents in one language for queries expressed in a different language, for example, SPIDER (SHERIDAN & BALLERINI) retrieves Italian documents with German queries. Others provide glosses in the same language as the query for documents in a second language, for example CINDOR (LIDDY). See DIEKMA & OARD in this volume for a full treatment of cross-language retrieval.

Aims to provide universal access have led to novel physical interfaces for a variety of users with special needs. Various approaches to interfaces for blind or visually impaired users have been developed, including: musical tones (MEREU & KAZMAN), speech-based web browsers (RAMAN) and screen magnification and cursor control facilities for low-vision users (KLINE & GLINERT). One group has even developed a user interface management system that allows interface designers to create parallel interfaces for sighted and blind users (SAVIDIS & STEPHANIDIS). Other researchers have focused on building and testing interfaces for the elderly. For example, OGOZALEK found that elderly users preferred a multimedia version of a pharmacopoeia to a text-only version and WORDEN ET AL. demonstrated that use of area cursor (larger than normal activation area) and sticky icons (decreasing cursor movement speed on and near icons, which in effect makes the icon region kinesthetically larger) decreases target selection times by as much as fifty-percent. There is a long history of interface designs specialized for children in educational settings (e.g., DRUIN & SOLOMON) and BORGMAN ET AL. have led the development of OPAC interfaces appropriate for children.

The absence of an appropriate interface for one's needs is as much a disadvantage as the lack of computers or information access. As computing becomes more ubiquitous, a fundamental challenge is to develop alternative interfaces that allow users to select and customize interfaces that best suit their personal needs. DILLON & WATSON argue for more studies of individual user differences beyond task and system experience so designers may more fully take such differences into account when designing interfaces. Having recovered from the failed promises of artificial intelligence approaches to user modeling, designers currently provide users with an array of preference setting options and wizards that model specific subtasks under user control. The current debate about intelligent agents that automatically adapt and perform independent of user control (e.g., automatic query expansion and web-based filtering robots) versus rich alternatives under strict user control are best exemplified by the CHI '97 panel debate featuring MAES and SHNEIDERMAN. These respective perspectives are well represented in publications such as MAES and SHNEIDERMAN (IN PRESS, see also BELKIN, 1996). The history of computing has been a litany of systems that depended on the outstanding abilities of humans to adapt to the environment, and unsuccessful efforts to automate intellectual activities. Applied wisdom suggests that designers should aim to give people control over powerful tools in a symbiotic manner to optimize human abilities to think, create, and reflect, and computer capabilities to store, display, and retrieve. Users may welcome or reject increasing numbers of mental prosthetics but they should always be free to make the choice and in the former case, should always maintain full control over the cooperative activity.

Toward Ubiquitous Access

Information seeking is always embedded in the larger tasks of work, learning, and play. Driven by distributed, mobile, inexpensive technologies, we are getting closer to WEISER'S vision of ubiquitous computing. In such a context, people can design information modules that fit into an infrastructure where information objects and the physical tools to create, access, and manipulate them are always present and assumed as an essential element of the environment. Freeing people from the tethers of office workstations will allow electronic information seeking to be embedded in our larger life activities. The vision depends on an information environment where context is unbounded, all types of content are available, and the tasks and information interactions are integrated with and customized to user needs and preferences.

Multimedia. The computational power, mass storage, and bandwidth improvements in recent years allow even modest workstations to deliver multimedia information. Digital libraries of texts, images, sound recordings, animations, and video as well as a variety of active templates and programs are emerging, although there is much interface design research needed to make these materials accessible and usable. Most multimedia access depends on linguistic cataloging to create MARC-like records for access. See DUGGAN for an overview of access, TURNER for a comparison of user and indexer term assignment, and MOSTAFA for a review of still image retrieval. These approaches are now augmented by a variety of signal-processing and computational techniques to distinguish multimedia objects. The fundamental design challenges are deciding what levels of representation to use and what control mechanisms to provide to users.

The challenges of locating, skimming, and using image and video objects have been addressed on several fronts. Still image and video indexing based on visual attributes such as color, luminosity, and motion (see GUPTA ET AL. for an overview) have been integrated into digital library solutions such as Informedia at Carnegie Mellon University (WACTLAR ET AL.) and Blobworld at the University of California at

Berkeley (WILENSKY), and in collaborative learning communities such as the Baltimore Learning Community (ROSE ET AL.). The Informedia interface allows speech query or typed text input and displays video skims that allow users to quickly extract the gist of television news clips. The Blobsworld interface uses image segmentation based on combining color and texture features to allow users to provide relevance feedback for key parts of a still image. The early prototypes of the interface allow users to assign weights to a variety of visual attributes and leverage the Cheshire (LARSON) retrieval engine. The BLC Project interface allows teachers to preview video clips by displaying a textual bibliographic record along with a choice of video surrogates. The slide show video surrogate displays key frames at rates controllable by the user, or users may choose the storyboard surrogate that displays static key frames. The video display tool is embedded in a larger dynamic query search interface that closely couples queries and results to provide visual overviews for the entire multimedia corpus that also includes still images, web sites, audio clips, and integrated instructional modules.

Some designers have proposed visual languages for query specification in image databases. NISHIYAMA ET AL developed an interface that allowed users to select icons, colors, and image attributes to pose queries for still images. The SAGEBOOK system (CHUAH ET AL.) allows users to sketch and edit queries as part of a larger multimedia system. Interfaces to support video browsing are under construction in several quarters. RORVIG demonstrated a video abstracting technique to rapidly scan NASA videos, and the authors have conducted empirical studies of interface design parameters such as display rates, number of concurrent displays, and storyboard layouts (KOMLODI & MARCHIONINI). To preserve bandwidth in a video meeting environment, YAMAASHI ET AL. provided an interface that allows users to select from among multiple video windows, one which presents full resolution views while others are presented in low resolution. Several color-based query systems that allow users to specify color attributes and use relevance feedback to refine image retrieval are in practical use. For example, IBM’s Query by Image Content (QBIC) system is used in the art slide collection at University of California Davis (HOLT ET AL.). Other systems use a combination of user query techniques. For example, BESSER describes the Berkeley Image Database System that provides access to multiple collections and supports linguistic descriptors as well as visual attribute queries, and MOSTAFA & DILLON report empirical results that demonstrate the efficacy of combining linguistic and visual query attributes.

The bulk of the work on audio interfaces has been related to speech input, which becomes more essential as personal digital assistants (PDAs) and digital cell phones are more commonly deployed. SCHMANDT and his MIT colleagues have led the best ongoing work on audio data. YANKELOVICH ET AL. provide an excellent overview of the issues related to speech-based user interfaces and argue that speech interfaces should be created with speech behavior in mind rather than trying to translate graphical interfaces into speech-based interfaces. FERNSTROM & BANNON have developed a sonic browsing system that gives users a starfield display to interactively retrieve music. RESNICK & VIRZI provide an analysis of the design space for selection-based audio interfaces such as phone menus and PDAs. ARONS created the SPEECHSKIMMER system that allows users to choose the level of skim desired by using joystick or touchpad controls. Given the amount of work being done on multimedia at the time of this review, we are certain to see a plethora of new interface designs in the near future.

Multiple I/O and Network Objects. The addition of the mouse to keyboard-based input provided a user acceptance path for multiple input devices and portended the current developments in interfaces that give users multiple input and output mechanisms for interacting with information. JACOB ET AL. as part of an NSF workshop to define HCI research directions summarized HCI research related to input and output devices and provided a framework for research on multiple and multimodal devices, including those that gather inputs automatically. The trends point toward coordinated, multiple input devices, including those that monitor human physiology (e.g., heartrate, electrical activity) and behavior (e.g., eyetracking). Early work on the efficacy of touch panels (POTTER ET AL.) has been augmented with the development of specialized interface devices that use lipreading for enhancing speech (PETAJAN ET AL.), facial displays for input and output (WALKER ET AL.), baton-based controls for music (BORCHERS), pointing/gesturing alternatives (GRAHAM & MACKENZIE), and gesture-to-speech conversions (FELS & HINTON). The development of PDAs has been facilitated by a long stream of work on pen-based input that includes handwriting recognition (e.g., RHYNE & WOLF), pen-based shorthands and selections (e.g., KURTENBACH & BUXTON), and speech input techniques (e.g., SCHMANDT). All these specialized devices suggest alternatives for different tasks and users, and opportunities for multimodal interactions, but a key challenge is how to integrate the various techniques in a single design. User-selectable alternative interface designs seem most promising in this regard.

Interfaces to control remote effectors (telepresence) or virtual objects (virtual reality) have attracted considerable attention for applications ranging from remote surgery to education, information retrieval and entertainment. SPRING and NEWBY provide overviews for virtual reality issues in information science. The primary metaphor of VR and telepresence is entering a world or controlling objects in remote places. Ubiquitous access brings computational power wherever one is rather than projecting oneself through technology. This perhaps culminates most radically in wearable computing. Early developments at MIT and Carnegie Mellon University have led to a variety of applications and a symposium on wearable computing (at MIT in October 1997). The applications range from "rememberance agents" that remind users about things to do based on context, and "nomadic radio" that keeps one in constant communication, to job-specific devices that assist technicians in tight spaces (BASS). Although present implementations for general use are clumsy and intrusive (e.g., small video monitors attached to glasses, single-hand input devices, and computer systems strapped to the waist), we can surely expect wearable devices and clothing that monitor our physiology and provide on-demand access to information resources wherever we are.

Information-seeking research has broadened in the recent past as a result of technology push. Multimedia retrieval challenges and web-based resources allow information seekers to focus on information objects at many levels of granularity rather than only at the document or bibliographic pointer levels. For a given conceptual object such as an article in an electronic journal, the unit of information-seeking analysis may be the entire paper, an abstract or outline, a concordance or term-frequency distribution, a set of hyperlinked references, a list of all subsequent references to the paper, or a co-citation map display that contextualizes the paper in a larger information space, not to mention active displays for figures or program code attached to the paper. As these "views" of the document can be automatically generated, information seekers will come to expect (and be expected to) specify the granularity for both search and display. Given the expertise required of professional intermediaries using online systems such as DIALOG to field-delimit queries and specify print formats, significant interface challenges lie ahead for end users seeking information in the WWW. For example, a query to the Library of Congress American Memory site may yield a hit list that mixes finding aids, entire image collections, and specific images or manuscripts. MARCHIONINI ET AL (in press). developed result displays that indicate the different granularities of objects available for each hit and the granularity level that yielded the hit. This kind of added value result display requires that part-whole and other relationship links are computable (or are manually added in the corpus).

The design challenges of many levels of information object granularity are exacerbated by distributed systems. Remote objects require naming that is, unlike one's personal file directory schemes, not solely dependent on a single user. For example, compare managing the bookmarks in a web browser with managing the different files on an office workstation. Thus, new standards for naming or new intermediary naming services will be needed—a problem well-recognized by the digital library community (e.g., see DLIB)--along with interfaces that support the entire range of user sophistication.

Enhanced Direct Manipulation and Customized Views. Perhaps the most important development for information seeking is the continued integration of the query and results steps in the information seeking process and closer coupling of interactivity factors. This integration is driven by several parallel developments: empirical and technical reinforcement of user browsing as an important information-seeking strategy, advances in information visualization techniques, and interface designs that incorporate multiple levels and alternative representations for information objects. Interfaces springing from these developments enhance users' ability to directly manipulate information objects and allow users to choose and customize interfaces best suited to their needs.

Browsing has always been recognized as important in libraries, but work in the first two generations of electronic information seeking was almost exclusively concerned with analytical search that depends on carefully planned queries and precise reformulations. BATES' (1989) berry-picking model of search, empirical studies of end user behavior (MARCHIONINI, 1995), and recent work by PIROLLI on information foraging illustrate the interest in supporting browsing in search systems. Browsing becomes much more important in multimedia databases and in digital libraries where consistent metadata is not available across all information objects. See CHANG & RICE for a review of browsing research and SPINK & LOSEE for a review of the importance of feedback in information retrieval. Hypertext systems served as the technical force for more interactive search in the 1980's where embedded menus (SHNEIDERMAN, 1998) and button selections made navigation (a form of browsing), the primary user control mechanism for seeking information. The WWW has multiplied this effect so that WWW-based search combines query specification and link selections. This combination of analytical and browse strategies is perhaps most strongly illustrated in GOLOVCHINSKY & CHIGNELL, who have developed systems in which queries and links are synonymous. In their VOIR interface, users iteratively select newspaper articles, which are used as queries to return new displays of articles that may again be used in a relevance feedback cycle to find the best articles to meet needs.

Improved hardware has led to new work in information visualization. WILLIAMS ET AL. review progress in scientific visualization techniques, here we focus on how such techniques are applied to user interfaces to support more interactive information seeking. The problem of displaying many related objects in limited display areas was addressed by FURNAS, who proposed using fisheye views of information spaces so users could focus on information objects of interest while maintaining their context. Other work aims to provide high-level overviews of information spaces through use of visual abstractions. LIN has used a Kohonen feature map algorithm to create semantic maps that allow users to visualize a high-dimensional document space in two dimensions where size of region represents frequency (importance) of concepts and region proximities correspond to semantic similarity. CHEN and his colleagues in their digital library interfaces have also used Lin's approach. Other researchers have concentrated on giving users the ability to customize visualizations for information spaces. KORFHAGE and his group have developed the GUIDO and VIBE systems that use points of interest (POIs) as visual objects users may specify to view the document space. The POIs represent any objects (e.g., a query, a profile, a relevant document) to which the user wants to compare the documents in the corpus.

To help users better understand and manipulate the results of queries, HEARST created the Tilebars interface that gives a visual display for the frequency of each query term by text section for each hit. This is a very effective visualization for understanding not only which documents are relevant in a list, but also for considering the most relevant sections in each document. This interface also illustrates how information seekers may gain views of results at different granularities. NATION created the WEBTOC interface to allow users to see a table of contents view of a collection or object, including the size and data type for each component. The LIFELINES interface (PLAISANT ET AL.) allows users to visualize information chronologically along easily rescalable lines displaying color-coded attributes. Leveraging interactive systems and clustering algorithms, CUTTING ET AL. developed the SCATTER/GATHER interface that allows users to select clusters from a display produced by a clustering algorithm, gathering them into a subset that is then used to re-cluster the database.

Two strong threads in user interface research for information seeking are to improve the direct manipulation interfaces of earlier days to closely couple queries, results, and interactions, and to augment linguistic interfaces with visual features. In most cases, these threads were integrated into advanced information seeking systems.

The work of CARD and his colleagues at Xerox Parc provided a sequence of these interfaces. These interfaces included the Perspective Wall (CARD ET AL. b) that used 3D perspective to allow users to visualize large document spaces; cone trees, cam trees, and the Hyperbolic Browser interfaces that allow users to see and directly manipulate thousands of information objects; and the Web Book and Web Forager (CARD ET AL.) that use a book metaphor for web browsing. A second ongoing line of research is headed by SHNEIDERMAN at the University of Maryland where a series of dynamic query interfaces were developed for a variety of applications. Dynamic query (DQ) interfaces (AHLBERG ET AL; SHNEIDERMAN) provide visual displays for the corpus and control widgets such a sliders and selection buttons for probing the corpus, i.e., dynamically querying the interface in an exploratory way where the query and results are tightly coupled. The visual display, in many cases a "starfield" display, maps information objects onto a grid defined by two key attributes. The attributes may be redefined according to user needs and the display is immediately updated as control widgets are adjusted. In effect, users may issue scores of queries by moving a slider for an attribute of interest and watching the starfield update for each slider movement. A variety of applications have been implemented using the DQ approach, including finding homes (Williamson), films (Ahlberg), NASA research documents (DOAN ET AL.), Library of Congress digital collections (MARCHIONINI ET AL., in press), and multimedia instructional resources (ROSE ET AL.). The key requirement for this type of interactivity is having all the attribute data immediately available. For very large collections, a hierarchical set of starfield displays is provided that allows network transfer of the appropriate partition of metadata for each starfield display. FOX ET AL. have developed the ENVISION system that represents information objects and their frequencies on a grid layout that supports dynamic query interactions.

These interfaces provide users with opportunities for examining information objects (whether these are entire corpuses or specific documents) at multiple levels and from specialized viewpoints. Interface mechanisms such as MAGIC LENS tools have been applied to dynamic query designs (FISHKIN & STONE). In such implementations, filters for key attributes are built into lens tools that users may grab and pass over displays as query operators. What "shows through" the lens is the filtered results, thus allowing users to perform rapid, exploratory probes of the corpus. Several researchers have created interfaces to allow users to view complex hierarchical objects or find structure in object collections. An example of the former is MUKHERJEA ET. AL who developed algorithms to display alternative hierarchical views for hypermedia based on clustering; users can select from several different visualization options. SHIPMAN ET AL. used studies of how people arrange text fragments into categories as the basis for the VIKI interface that suggests composite groupings for objects to facilitate exploration. A highly generalized mechanism for managing multiple levels of abstraction in a direct manipulation manner is the continuous zoom. Zooming and panning offer provocative possibilities for accessing information in hierarchical structures. Originally proposed by PERLIN, the PAD++ interface (BEDERSON & HOLLAN) allows users to control an infinitely-scalable surface with a three-button mouse. This interface is especially effective for timelines, complex diagrams, and highly structured documents. RENNISON has applied zooming and panning in an electronic text environment and LIEBERMAN has demonstrated the effectiveness of zooming for geographic data.

Although these interfaces adopt different widgets, they share the common goal of enhancing users' abilities to combine analytical and browse information-seeking strategies, view databases at aggregate and detailed levels according to specific attributes, and generally interact with the data in exploratory ways. The advantages of increased interactivity in a query environment were demonstrated by KOENEMANN & BELKIN and the interfaces emerging for today's WWW environment tend to maximize interactivity. Although the integration of query and result subprocesses of the information-seeking process has finally become more closely coupled, much work remains to integrate problem definition and information manipulation and usage subprocesses. HENDRY & HARPER's SKETCHTRIEVE system aims to go beyond information exploration to support information processing through tools for comparing documents and allowing annotations on documents and linkages among documents. There is certainly much more progress to be made if interfaces for information seeking are to support the entire process, let alone the process embedded in larger work or play settings.

Directions

The WWW in many ways stymied the advance of user interface research for a few years by providing a minimalist platform that did not maintain state, did not support windows or sophisticated menuing, and limited user interactions to selections and simple form fill ins. The overwhelming advantage of such a simple platform soon became apparent and the subsequent improvements as HTML was enriched and Java applets and applications evolved have allowed user interface research and development advances to find applications in the WWW environment. Search engines have evolved from simple forms-based interfaces that returned long lists of ranked web pages to interfaces that provide fixed entry categories (e.g., YAHOO) and give users many options for formulations (e.g., limiting by sources, fields, data types, and variants), provide results viewing options, and support relevance feedback (SHNEIDERMAN ET AL, 1997). As the WWW infrastructure continues to develop, the user interface techniques created for standalone environments will continue to migrate to WWW interfaces.

New challenges for interface designers are emerging as web-interface designs for "push" technology (targeted channels of advertising or specialized services automatically sent to users) compete with designs for "pull" technology (users selecting what appears). An excellent interface design from the perspective of the intermediary service that uses pay-for-performance techniques to get user attention may be extremely annoying to users who do not wish to have their various browser clients affected. Filtering alternatives that will inevitably emerge offer new interface design challenges for giving users multiple alternatives and ways to manage those alternatives. Interfaces for the web will differ by task/business just as much as they do by user preference, for example, government sites and search engine sites may want interfaces that encourage short sessions and quick exits, while sales and entertainment services will want interfaces that maintain user attention. In all cases, a design guideline that is gaining consensus is to minimize mouse clicks and quickly bring relevant information to the user. Design prototypes for the Library of Congress National Digital Library Project (MARCHIONINI ET AL.) used compressed layouts to flatten hierarchies and minimize user clicks. Although this puts more words on a screen, it serves to save potentially disorienting jumps and provides a better overview of the site. Likewise, corporate Intranet designs will continue to minimize form to accommodate function in work environments. These information-rich designs will not be effective for entertainment or news applications that depend heavily on design novelty and continually changing content to attract users. The age-old tradeoffs of form and function today challenge interface designers as the tensions grow among various interface stakeholders and as we move toward universal access and more web-based applications.

Perhaps the greatest research challenges are to develop alternative interfaces that meet the needs of wide-ranging sets of users, and models and mechanisms for optimally mapping interfaces to problem situations. In addition to the obvious work needed on user behavior, we must reconceptualize our view of information systems as distinct entities to see them as elements embedded in a larger user-information milieu. Information systems might be considered to be more like geographic information systems (GIS) that store spatial data that may then be flexibly manifested according to user needs. In a GIS, the map displayed is a thematic view of the underlying data and may be easily changed according to the needs of the user (LAURINI & THOMPSON). Increasingly, web pages will be generated on the fly from back end database stores and customized not only to user query but also to profiles and contexts. Additionally, user interfaces that support information seeking must allow users to view information according to their needs. To do so requires rich and well-documented data underneath (the various representations for information) as well as the user control mechanisms for defining which view best meets the need. Extended markup language (XML) provides potential for client-side customized views of generic data.

The information-seeking interface should be made part of the user's larger work environment so that interfaces support brainstorming, problem definition before search, and information manipulation, usage, and communication after search. Today's web browser interfaces that integrate web access, communication, and editing are a clear step in this direction. The Microsoft OS/browser issue currently receiving U.S. Justice Department attention is largely about such issues.

Finally, new models of information retrieval are needed that consider users as individuals so that the same query posed by two different people actually returns different and differently ranked documents (e.g., LOSEE proposed using Gray codes for this purpose); that are information-oriented (object) rather than document-oriented; and that support interoperation across databases (including merging of results). Such IR models will help interface designers to create more personalized and interactive experiences for information seekers.

CONCLUSION

User interfaces that support information seeking have benefited from the parallel developments of research on the information seeking process and human-computer interaction, which in turn have been strongly driven by technology development. Interface design has become more user-centered and continues to attend to serving the needs of larger portions of the population toward the goal of universal access. In addition to the variety universal access implies, interface design has begun to take the user's context into account to establish a balance among user needs, organizational setting and task, and system capabilities.

Information systems and interfaces have caused information science research to elucidate more precise models of information-seeking strategies. Although early developments focused on query specification and subsequent development provided informal browsing support, there is a trend toward more mature interfaces that support ranges of information-seeking strategies with direct manipulation and highly visual control mechanisms. Today's interface research aims to support user search for and examination of multimedia information at various levels of granularity. These interfaces increasingly provide different coordinated multi-modal input and output devices.

User interface research in the late 1990's points toward ubiquitous access to information objects. Most importantly, this access is embedded in the larger information activities of life and customizable to individual preferences and abilities.

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