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Human–information interaction research and development

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ABSTRACT

The information field continues to evolve rapidly as digital technology changes the very nature of information and how people interact with each other and with information. This article argues that the past 30 years have seen a shift from distinct emphases on information, individual people, and specific technologies to emphases on the interactions among more diverse forms and amounts of information, people, and technologies. Human–information interaction shifts the foci of all aspects of information work; blurs boundaries between information objects, technology, and people; and creates new forms of information. This article discusses changes in each of these components of information and trends and challenges surrounding the study of their interactions are presented.

1. Introduction

The information field continues to grow in importance as more people work in the information and service industries and digital media assume greater roles in education and entertainment. The growth in practical impact has been reflected in the growth of research devoted to information. This article reflects on how information research has shifted from emphases on discrete elements of information toward an ecological account of human–information interaction. The three classical elements of the information field have been information objects[1] (e.g., books, articles, and other physical records); humans who create, manage, and use the objects to form mental representations; and the technologies that capture, store, transmit, and manage information objects. In the second half of the twentieth century, researchers shifted away from studying the acquisition, organization, and management of collections of information objects. Instead, they began emphasizing human and technological elements independently, as well as considering their relationships to communication and information transfer. In the late 1970s, scholars looking toward the last decades of the twentieth century posed research agendas that were more human-centered. The field became more user-oriented, albeit through the lens of technical changes in how people create and access information objects. For example, one report summarized the results from a set of meetings devoted to establishing a research agenda for the field (Cuadra Associates, 1982). Nine (45%) of the twenty research projects organized into six categories fell in the information users and use category. The 1980s and 1990s saw these trends born out in the field's research journals and in the explosion of conferences devoted to information retrieval, human–computer interaction, and digital libraries.

Many researchers chose a scientific and reductionist approach to study the elements of the information field independently, with an eye toward creating better information systems and services. These efforts led to useful systems (e.g., search engines, online catalogs, citation indexes, virtual reference services, and multimedia digital libraries), but no unified theory of information. The design community also influenced information science by aiming to create transparent systems that allowed people to focus on the problems at hand (e.g., Weiser's calm technology; Weiser & Brown, 1995). A primary approach to making transparent the technology that modern information depends upon is to couple people and information closely. A quarter-century ago, Shneiderman (1983) called this approach “direct manipulation.” Due to efforts to understand all aspects of information activity and design trends and more directly involve humans in controlling these activities, researchers are increasingly forced to take an ecological approach to information research. This approach helps researchers to understand phenomena involving interdependent elements that interact continuously to create new outputs and emergent events. Thus, a fundamental challenge of the information field today is explaining how people interact with the objects that they make. This article summarizes this state of research and development by considering the status of the three classical elements of the information field (objects, people, technology). It then examines their interactions and integration from a more ecological perspective.

2. Terminological caveats

People may consider this journal's articles to be part of library science, information and library science, information studies, informatics, or any number of other variations on the information field.

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[1] Using the more general term object instead of artifact admits the increasing range of products produced by machines or emergent in human-machine networks.

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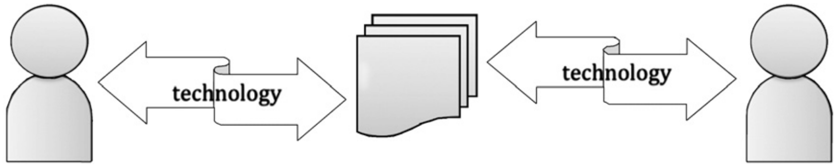

Fig. 1. Information centric view.

This study uses the term *information* as the name of the field (the phenomena of interest) and *information science* as the activity that researchers, developers, and information professionals undertake. Information has four distinct meanings. Three were articulated by Buckland (1991): information as act, information as knowledge in the head, and information as thing. The fourth, temporal states in cyberspace, is an emerging kind of information that results from human–information interaction. One particularly important part of the fourth sense of information is the *proflection* of self in cyberspace. *Proflection* consists of an individual's conscious and unconscious projections and the reflections that other people and machines create to those projections (e.g., links and annotations).

The term *information object* includes the intellectual products of information activity and the recording of real world objects and events. This follows Buckland (1991) sense of information as thing. Information objects include a storage format (physical or digital) and one or more forms of human usable expressions[2] (e.g., visual, aural, and tactile). Information objects have historically been crafted by humans who map information in their mind/bodies onto forms of expression according to culturally significant representation schemes. Due to large-scale network interactions among people and digital information objects, new kinds of globally-distributed, instantaneous information objects related to a person or group have emerged. People often use tools to craft information objects. In the case of digital objects, these tools often themselves are the medium of persistence and consumption for the information object. People consume or experience information objects by applying their senses and possibly transforming the objects into information in the head (in the Buckland (1991) sense).

Wellisch (1972) traced the terminological history of the information field from *library economy* in the late 19th century to *documentation* through the first half of the 20th century and to *information science* in post-World War II period. He pointed out the many flaws of the term *information science* and suggested using the term *informatics*. Today, the term *information* alone is used in the name of some schools with faculty who engage in research and teaching about a much broader notion than even the general term *information science*. The field has moved from managing extant objects to considering the genesis, distribution, management, use, reuse, and preservation of all aspects of human intellectual effort, including those delegated to machines. Part of this broadening is due to the social and political tendencies of human groups to accrue influence. Another part is due to the blurring of boundaries between human thought; communication; and the creation, management, and consumption of intellectual products.

It is this broadening that is of interest here, especially the roles of tools and representational schemas for information objects in stimulating these blurs. What becomes information depends on humans' using tools to create, store, and experience information objects in increasingly faster cycles that blur boundaries. Thus, the information field is evolving in several ways:

- from focus on stable artifacts to grappling with how people and machines interact with dynamic, morphing information objects
- from focus on individual information seekers and managers as rational cognitive actors to considering embodied minds in a cyber collective
- from issues of physical object management to issues of scale, layering, and boundary blurs
- from information management to identity management as instantiated in user profiles, filters (e.g., spam), and personal health records.

This shift is illustrated in the following two figures. Figure 1 depicts the classical information-centric view of the information field. Objects (e.g., documents, books, and films) are in the center; people create and access these objects through various technologies. Figure 2 depicts an interaction-centric view of information; people (as individuals and often as groups) and streams of active objects interact in a technological substrate (cyberspace, represented by the cloud) that itself affects the people and objects. The interactions create new objects (logs, system states) and all elements, including the objects and cyberspace evolve over time. Research and development in such an environment requires an ecological approach that attends to mutual interactions among all elements of the environment.

3. Objects and content

Classically, information and library science (ILS, a late 20th-century bridge term for the field) is concerned with collections of objects, the organizational schemes for collections of these objects, and the services associated with those collections. Traditionally, the objects have been physical artifacts that occupy space and have discrete, tangible boundaries. There are three aspects of these objects that bear ILS study:

1. ideas in the mind of humans or rules in the work processes of systems
2. tokens that instantiate the objects to stand as representations for those ideas or rules
3. storage schemes for aggregations of these objects.

Study of the genesis and expression of ideas was generally left to epistemology. In the 20th century, cognitive science and study of creating rules for organizations or machines were generally left to management and software engineering. Study of individual objects (e.g., books, documents, paintings, musical scores, and videos) and objects created by people or systems (e.g., data streams and records) was generally left to specific academic disciplines, publishing, or computer science. ILS tended to study the organization of information objects: how they could best be stored, retrieved, and preserved for future access. Thus, ILS developed theories and practices related to critical issues. These included classification schemes that divided the universe of knowledge into discrete categories, cataloging and labeling procedures that assigned specific objects to those categories and added authoritative identifiers to the objects, abstracting procedures that compressed the gist of content into human-consumable summaries, retrieval processes that matched expressions of information need onto objects, relationships between and among content objects, and curatorial processes that protected content objects from physical deterioration

[2] This assumes that any human form of expression can ultimately be mapped onto analog or digital signals for machine processing of some kind.

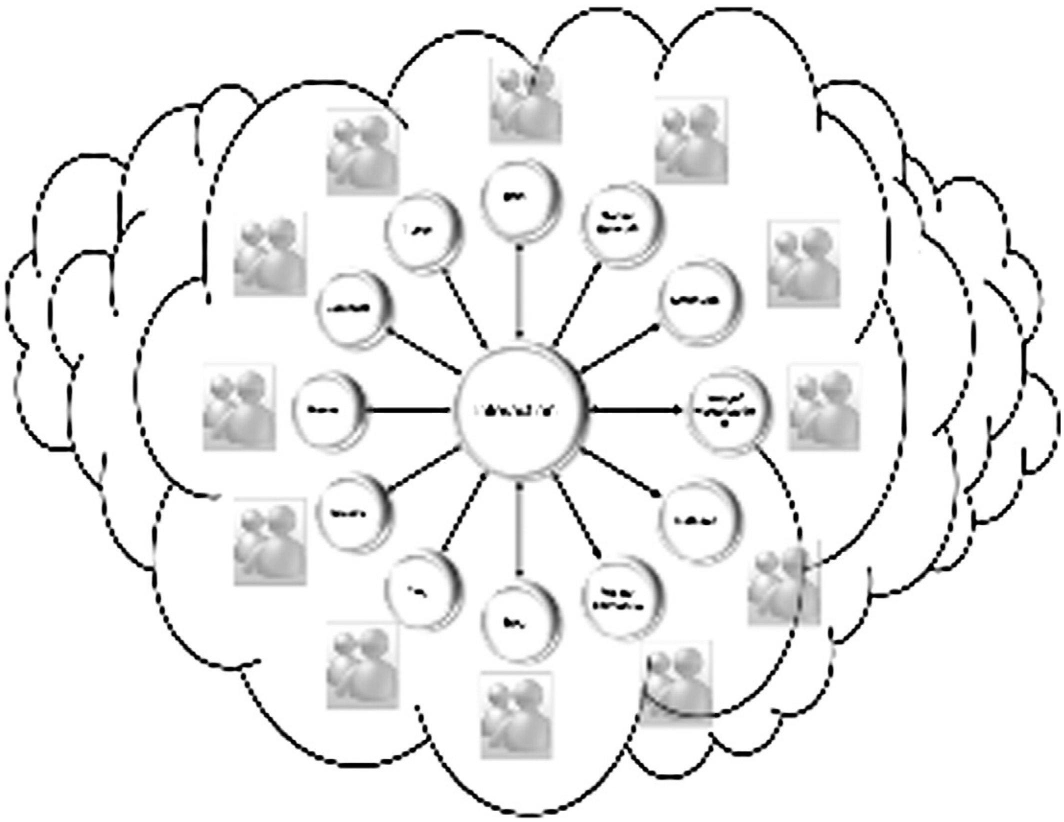

Fig. 2. Interaction-centric view.

and loss.[3] These theories and practices have been rooted in content representations that are physically static and text based, except in somewhat esoteric cases. The ubiquity of electronic technologies that has evolved over the past 30+ years has shaken the field at its very foundations because the characteristics of information objects have changed wildly.

The changes in the nature of information objects and how those objects are created and distributed fall into two classes. First, the dominance of textual representations for knowledge is challenged by visual, aural, and various multimedia forms of expression. One way to think about different forms of expression is as a continuum organized by level of coding (i.e., the amount of decoding a human must do to interpret the expression smoothly[4]). At one extreme are statistics, genetic sequences, and computer code—all require substantial metadata, training, and mental effort to interpret. At the other extreme lie images, film, music, and immersive environments—all require few culturally bound decodings to understand. Text lies in the middle of this continuum and stands as the most pervasive form of stored human expression. Stored oral language lies between text and imagery and will surely take on increased importance. New technologies over the last century and a half (e.g., cameras and the telegraph) have begun to change the distribution of forms of expressions dramatically, making them much more diverse and balanced. This diversity in forms of expression is abundantly evident today in the variety of electronic media used in all aspects of human existence. Music has become ubiquitous as more people sprout ear buds to access their MP3 players, satellite and Internet radio, and other aural information. One image-sharing service, Flickr™, has hundreds of millions of images and millions of users. Television is no longer a tethered medium; YouTube has become a globally massive campfire with 65,000 new videos added a day in late 2007. Blogs, wikis, and other social networking services are evolving to support the entire continuum of expression. Oblinger & Oblinger (1996) argued that the higher educational enterprise will necessarily be transformed because young people will demand the full range of media for the educational experience. It is not that text is no longer used, but rather that it is augmented with an increasing variety of alternative and multimedia expressions. These changes are due to advances in tools that support the easy creation and distribution of sound and visual expressions. They challenge information scientists and information professionals to discover new organization, storage, and access techniques.

The second factor that dramatically changes the nature of information objects, and therefore what information scholars study, is the large amount of information that is manifested digitally Digital representations are easy and inexpensive to copy without loss, and they transfer on massive scales easily. These well-known properties of digital artifacts have driven the digitization of existing forms of human expression, as well as the movement toward creating new expressions in digital form (born digital).[5]

Even more important than perfect replication and cheap mass distribution is the fact that digital expressions have the potential to encapsulate behavior within them. Two kinds of behavior are of interest. First, the ability to include hyperlinks for intra- and inter-object relationships has driven hypertext and hypermedia adoption, as manifested in the World Wide Web. Links are one-to-one relationships between two discrete digital objects. These link

[3] Clearly, ILS researchers have strayed beyond these issues to study how content is used and how content relates to human progress. However, the body of core research relates to the issues of content storage, retrieval, and preservation.

[4] Another way of thinking about this is to consider the amount of metadata that is needed to make sense of the information object.

[5] See Bolter (1991) for an analysis of the implications of electronic text.

destinations can be within the same document or across objects anywhere. As implemented today, hyperlinks tend to be static; once they are incorporated into a document, they do not change unless the document owner edits them. Thus, hyperlinks make documents semi-active by supporting direct, unidirectional jumps to other points in the global information space. Consider how even this simple and highly constrained behavior has affected knowledge creation, distribution, and human communication on the Web.

A more powerful kind of behavior lurks behind today's information environments that support simple one-to-one directed links. Early hypertext researchers created general models for typed and computed links (see Stotts, Furuta, & Cabarrus, 1998; Trigg & Weiser, 1986, Zellweger, 1989) that have not yet been instantiated in the web environment, but surely will in the near future. Digital objects have the inherent potential to contain program units—for example, if-then conditions. These if-then conditions allow new kinds of possibilities in the creator-consumer relationship. For example, objects can morph themselves based upon any number of spatial, temporal, or user conditions, even without external editing or manipulation. Thus, the digital book downloaded from Amazon today may render itself differently to someone across the street or across the world (e.g., depending on language). It may appear differently next year based on what one has read in the interim or whether a usage license remains valid. When combined with the trend toward multimedia forms of expression, programmatic behavior opens up new possibilities for expression and information interaction. Wikis illustrate what is possible with continually evolving information streams; however, current wikis depend on human edits rather than automated changes. A search engine's ranking of results or an e-commerce service's recommendations are based on changing world conditions, including the state of the user. These features hint at what is possible with conditional renderings based on instantaneous and historical external conditions. Most of these conditional renderings depend on centralized services rather than object encapsulation. However, the use of placeholder regions on Web pages that support search engine ads based on on-the-fly search conditions are increasingly common. They illustrate how search engines and other information services leverage user behavior and world events to influence human behavior. Conditional behavior on Web objects also allows designers to create systems that involve users in annotating, editing, ordering, and customizing viewing (i.e., interacting with content). Supporting user-controlled interactions with information is one of the goals in developing the Agileviews design framework (Marchionini, Geisler, & Brunk, 2000). This framework aims to give information seekers easily changeable views of information displays.

Thus far, there are no examples of conditional behaviors in video. In fact, video does not currently support simple hyperlinks. Mash ups and other creative reuses and integrations of digital expressions are a step in the direction where humans act to create new renderings on-the-fly. Performance artists have been exploring the nature of audience participation and the flow of ephemeral states over time. Paul Kaiser's *Loops* is an interactive, real-time portrait of dancer Merce Cunningham. Kaiser contributed the controlling software under open source licenses but wondered how best to document performances and parameter settings given that every performance is unique (http://www.openendedgroup.com/index.php/artworks/loops-2001-present/loops-ecology/). Miller (2004), a.k.a. Spooky DJ, is a practicing remix artist who has written about remix culture. As tools and techniques allow multimedia mash ups to include if-then kind of conditions, new challenges will emerge for information researchers and practitioners.

The long-standing efforts of the information field to support semantics (concepts rather than word tokens) have yielded some promising directions in text summarization (e.g., Mani & Maybury, 1999) and information synthesis (Blake & Pratt, 2006). An ongoing blurring challenge introduced by digital multimedia with behavior is how to handle streams of information such as RSS feeds, continuous click streams by people, and the massive flows of data from sensors of all kinds. For example, there are no rules for determining boundaries or deciding how much evolving metadata and context to include. The possibilities that digital representation offer are both stimulating and daunting. Unleashing the creative free associations of humankind on heavily laden, scalable information spaces excites our urges for novelty. Yet the potential chaos and perpetual overloading of the senses and mind with new, unending chains of novel linkages may lead to exasperation and dysfunction. The coming information space will contain both physical and digital representations, including the comfortable closure of physical information objects such as books with clear demarcations and endings. All of these must be considered in information theory and professional practice.

4. People

Rather than considering information as stand-alone objects to be acquired, managed, and retrieved, information researchers reason that they could better understand these information management problems by looking at how people seek and use information. The approaches taken to studying human–information activities are necessarily influenced by contemporaneous theories in psychology. For information science, the most influential psychological theory of the mid-twentieth century was the information-processing model of cognition. This theory was inspired by the cybernetic theories of Ross Ashby and Norbert Wiener, the development of analog and digital computing devices, and the linguistic theory of Noam Chomsky. The information-processing model of cognition was best articulated in the works of George Miller, Allen Newell, and Herbert Simon. They posited theories of thinking dependent on linear information flows that were strongly constrained by limited processing resources. Newell and Simon (1972) used methods such as asking people to think aloud while solving problems. They aimed to validate the information-processing models rooted in these qualitative data by creating computer programs that simulated simple problem-solving procedures. Although this type of cognitive model instantiated in software had some successes (e.g., the General Problem Solver), more particular rule-based approaches were embedded in expert systems. Johnson-Laird (1983) and others introduced the notion of mental models as programs in the human mind that define concepts and help people make plans. This body of work inspired a generation of information scientists to study information seeking by probing the thoughts of people conducting searches, simulating presumed cognitive functions with computer algorithms, and observing information behaviors in offices, libraries, and other settings. The strength of this trend is reflected in the Cuadra report (1982), as well as in the popularity of think-aloud methods and mental model frameworks for information studies.[6]

In parallel, the fields of computer science and psychology adopted the information-processing model of cognition and developed a new field known as human–computer interaction (HCI). The field included predictive models of simple human behaviors, such as perfect text editing (Card, Moran, & Newell, 1983). HCI user-centered design methods and usability study evaluation techniques were quickly adopted by information scientists, who aimed to understand information seeking and develop better information systems.[7] By the closing decades of the 20th century, most information programs had incorporated HCI into their training programs for information professionals.

As information retrieval (IR) became more important to scientific and economic progress, some IR researchers expanded the problem

[6] As of February 2008, the LISA database returned 45 papers with think aloud somewhere in the full bibliographic record and 28 papers with the term mental model.

[7] As of February 2008, the LISA database returned 1468 papers with human-computer interaction somewhere in the full bibliographic record.

space beyond including the human as part of information retrieval process. They shifted the focus directly onto the human–information seeker rather than on the information resource. The user-centered information work of Bates (1989), Belkin, Oddy, and Brooks (1982), and Saracevic and Kantor (1988) inspired information scientists to focus on information-seeking as a human problem-solving process. This shift in perspective is summed up simply with two notions: Information retrieval implies that the information exists. It focuses the problem on delivering the proper extant information (i.e., matching query and documents). Information seeking is broader and admits the possibility that information that meets the human need does not exist at all; it focuses on the information processing aspects of human problem solving. Most information training programs offer multiple courses on the information retrieval and information-seeking problems.

Thus, in two important research communities within the larger information field, human-centered information seeking has become an important approach to studying information phenomena. Marchionini (2006) argued that the intersection of these two communities from within HCI and IR defines an emerging human–computer information retrieval (HCIR) research agenda.

While information scientists have been developing new, more general theories of human information seeking and information behavior, the broader cognitive sciences have undergone radical shifts. They have departed from the stand-alone model of an information-processing system within the human body. They now take a more holistic view of humans as situated actors within an environment, which strongly influences their thought processes and behaviors. This environment includes one's body, the physical space surrounding the body, and other people and ideas in the physical and intellectual realm.

Vygotsky's notion of cultural mediation in learning and thought developed at the start of the twentieth century. Western cognitive scientists only discovered it in the second half of the century. This discovery stimulated theories of situated cognition (e.g., Brown, Collins, & Duguid, 1989), distributed cognition (Hutchins, 1995), and more general social aspects of human behavior and social psychology. The idea that learning and thought do not take place in isolated minds but rather depend on social interaction represents a fundamental shift from the individual cognitive rationality illustrated in Descartes' famous phrase, "I think, therefore I am." This change in the view of human cognition is beginning to change the way researchers think about how people seek and use information. It is reflected in the interest in collaborative search and social networking systems on the Web that is a primary characteristic of Web 2.0 rhetoric.

Another major shift from the classical information-processing model of cognition is the recognition that cognition is not independent of the human body and the world in which it lives. This view of embodied cognition is well articulated by Clark (1997). His study provided empirical examples of how human and other mammals' behaviors are determined by physiological interactions among the body, the mind, and the environment. Johnson (1987, 2007) explained image understanding, art appreciation, and thought through multiple treatises on how mind and body are mutually important.

These developments in cognitive science have strongly influenced scholars in the information field who have shaped models of human information behavior (e.g., Fidel & Pejtersen, 2004; Ingwersen & Järvelin, 2005; Kuhlthau, 1988; Marchionini, 1995). The way that these developments in cognitive science are playing out in information schools is reflected in attention to study of collaborative work and how information resources influence that work; in studies of the intellectual relationships among people, ideas, and intellectual products via bibliometrics; and in the emerging studies of massively scaled social networks and social computing. Although a Web search is typically a physically solitary activity, it is increasingly clear that search takes place in a global setting of people and resources unlimited by space or time. Current efforts to define and study collaborative searches (e.g., Bruce et al., 2003; Morris & Horvitz, 2007) demonstrate that humans have become situated information actors rather than isolated cognitive actors.

5. Technology

Technology has been one of the primary drivers of these shifts in the information field. The technology of print that dominated the work of libraries and white collar professions in the twentieth century placed strong spatial constraints on managing information objects. These constraints necessitated creating layers of indexes that supported access and strongly separated access from use. Thus, in the past, the primary goal of libraries was providing access while leaving consumption and interpretation to the information seeker.

One of the most significant technical developments of the twentieth century was combining electronic storage and computational power to support access to full-text documents. The early Boolean search systems that came into large-scale commercial use in the 1960s and 1970s illustrated new scales of retrieval that became expected in professional settings. The development of more powerful computers allowed practical implementations of full-text, ranked retrieval models developed by Salton and others. These models leveraged word occurrences and co-occurrences in large full-text corpora, which raised user expectations even more. Networked computers led to linkages as additional sources of evidence for retrieval algorithms in the Web environment and created popular expectations of full-text access.

Computational power supports new kinds of analysis, aggregation, and comparison, all of which support better information seeking and use and increase user expectations. The capacity and price of mass storage technologies now easily rival the largest and most expensive physical information warehouses on the planet. In essence, it is becoming cheaper and easier to store everything created in digital form than to take the time and effort to select and dispose of drafts, errors, annoyances, and irrelevant information. Communication networks have enormous global reach at near instantaneous speeds. Devices to capture human utterances, gestures, performances, and physiological outputs support conscious and unconscious self-expression in new and inexpensive ways. Additionally, these tools have become not only more affordable and ubiquitous, but easier to use as they merge into popular culture and our capabilities, familiarity, and expectations evolve.

Because the products of our expressions are stored in digital form, people have created an array of editing and reuse tools that support repeated revision and massive sharing. Technical advances in representing digital information have also been made, but at present, much work remains to be done. High-resolution displays for visually manifested information find practical use in all shapes and sizes, from wall-size displays to tiny screens on cell phones and children's toys such as the Leapster. Portable headphones make music and conversation ubiquitous. All these advances represent base technological developments that support cyberspace, or cyber infrastructure. From the broad information field perspective, these enabling technologies make search engines, content-sharing services (e.g., del.icio.us and flickr), and social environments like MySpace and Facebook possible. From a library and cultural memory perspective, digital libraries are based on integrated environments that assume that these enabling technological advances are persistently accessible.

All these technical developments have led to enormous quantities of digital bits available in a variety of human-consumable forms. Thus, the problem facing people has shifted from retrieving information to filtering it. Challenges for information scientists lie in new kinds of representations (e.g., data visualization), as well as in techniques for mining existing corpuses and filtering incoming streams (e.g., spam filtering). The research activity in these areas has become part of the mainstream digital library research and development agenda.

Digital libraries intend to make specific knowledge accessible to service populations without regard to the constraints of time and space. Ultimately they may become personal memory prosthetics and collaboration spaces. The early years of the digital library movement focused on integrating the base technologies of computation, storage, communication, acquisition, and display into workable systems. The more difficult challenges of selecting, annotating, and matching information artifacts to human needs remains a fundamental research and development problem. While this is difficult enough, support for the higher levels of Bloom's taxonomy and Taylor's value-added hierarchy is what would enable people to manage their proflections. Digital representation, as well as the multiple forms of expression that digital representation supports, blur the boundaries between an expression and its context. It is as if the noumenal clouds[8] in our mind that form, merge, and dissolve as long as synaptic activity exists have now become instantiated in a less ephemeral and more public mental space. One of the challenges of digital librarians is to identify the boundaries between the primary information object, its metadata, its relationships to other ideas and objects, the external linkages, annotations, usage traces others leave with it, and the history of the object over its life cycle. This includes all the behavioral executions initiated within the information object itself or by external forces such as other information objects, people, or machines. Thus, technology has evolved to be more closely coupled with information and people; information students are learning about holistic information systems like the Web rather than isolated technologies and information sources.

6. Human–information interaction

Interaction is a special kind of action that involves two or more entities and a set of reciprocities that effect changes to each entity. To characterize an interaction, it is necessary to specify the entities, the nature of the actions, the genesis of the actions (initiation), the amplitude (intensity) and frequency of the reciprocity cycles, and the resultant changes in the participating entities. In the case of human–information interaction, humans and information are the entities. Actions are mental and physical; interaction may be initiated by humans or information objects. The intensity of a specific cycle can be small (incremental) or large (epiphanies, deletions) and the frequencies slow or rapid and regular or chaotic. The changes are differences in mental states of the human and physical or digital states of information objects. Although all these characteristics of interaction are important, high-interaction experiences are typically determined by high reciprocity rates.

Theoretically, a human uses an object when there is little or no reciprocity or the feedback cycles are extremely limited and predictable. The term *interaction* is reserved for the situation in which the entities participate in several cycles of action that in turn cause changes in those entities. More practically, when human–information interaction is discussed in the information and computer science literatures, a human typically does something repetitive (e.g., click, read response, click again). The person experiences different information each time without regard to changes in the object used (i.e., the changes in the interacting entities are mainly one-sided). One claim of this paper is that humans are moving toward a potentially more symmetrical meaning of human–information interaction, where both humans and information objects evolve as a result of and throughout interaction.

It is very easy to grasp how people interact with each other and with other living entities (e.g., pets) because humans have so much personal experience with such interactions. There is a huge variety of mental and physical actions possible. Interactions can be initiated by any living entity involved in the interactions, or they can be mutually initiated. The cycles can be few or many and take place over seconds or years, and the resultant changes can be trivial (e.g., excuse my reach) or life altering (e.g., your money or your life). Because humans have extensive experiences with a diverse range of interactions with a seemingly limitless range of feedback possibilities, interactions with non-living entities seem impoverished to the point of being non-interactive. However, it is increasingly easy to accept that people interact with inanimate objects as the modern built world leverages technologies to give our artifacts capabilities to change form and to initiate interaction. Many children's toys now have simple sensors and affectors that allow the toys to initiate interaction—for example, some signal “play with me” one minute after movement has ceased. Terms such as “intelligent” buildings, highways, automobiles, and homes actually indicate infrastructural artifacts that may initiate actions and are available for interaction. Mitchell (2003) Me+ is an interesting explication of this phenomenon. It gives many examples of how the built world is becoming an extension and appendage of our selves.

It is less apparent what it means for people to interact with *information*. On one hand, since digital forms of information are so ubiquitous and require some kind of technology to facilitate human perception, people interact with the technology as an intermediary. This intermediate interaction with technology is tangible and necessary (but not sufficient) to accomplish information goals. Because early electronic technologies were so foreign to common human experience, human–computer interaction has classically addressed interaction with the technology. This study considers what it means to interact with information rather than another human or a computer.

In the case of information as mental state, human interactions are internal. The mental state of an individual at any instant in time is defined by a network of activated connections among neuronal cells in the brain. These networks are concepts, impressions, and active memories. Their evolutions over time are called *thought*. These networks can also be called *noumenal clouds* because they are constantly shifting and evolving. Information as mental state is thus a set of noumenal clouds at some point in time. Interactions are the strengthened or dampened firings of synapses that shift the cloud patterns over time. Adding more energy to one cloud (concept) may dampen, merge, or dissipate other clouds. External stimuli reach synaptic junctions to alter the shape and energy of these noumenal clouds as another kind of interaction with the external world. Because humans control their higher-level mental activity, they control the interaction of information by mulling over ideas and impressions and admitting external signals that change their mental state. Repetitive cloud patterns create familiar (memorable) concepts or impressions, although each re-instantiation is a unique neural pattern. Highly familiar patterns are replicated quickly and with few differences, whereas less familiar or complex patterns are less similar over time. This fluid model of information interaction in the head also serves as a model for the collective state of cyberspace: Linkages are strong or weak over time so that search result sets, Wikipedia articles, and personal propensities to respond to stimuli exist in different phases of stability. Whether considering this interaction of information in the brain/mind as a kind of synaptic flow of ionic activations or taking a more spiritual view of the mind/soul, the notion that mental information is interactive obtains.

The case of interaction with information objects can be more precisely considered. However, the ordinary sense of activity is more of “use” than “interaction” because in the past humans have had few

[8] The shifting networks of synaptic activations that drive human thinking are known as noumenal clouds because they tend to be amorphous and ephemeral (Marchionini, 1995). This is, of course, a gross oversimplification of the neuronal doctrine developed by Cajal a century ago. It serves as metaphor for the continual cognition and affect that is sometimes depicted by positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) imagery at specific time slices.

tangible experiences with information objects changing as they use them. As the technology to store and represent information continues to be integrated more gracefully, people can experience content more directly rather than focusing attention on the intermediary representational system. Increasingly, the possibilities for interaction include physical acts, but they tend more toward mental on the part of human entities. The acts of the information objects are no longer strictly encapsulated in the object but may be distributed globally. They are thus more akin to the noumenal cloud activity of humans than the comfortable stability of an epigram on stone. Although people will typically initiate interaction with information objects, the pervasiveness of tagging, annotation, spam, advertising, and subscription feeds illustrate how digital objects increasingly invite at least reactions and sometimes interaction.

Because the electronic medium supports very high reciprocity rates, the potential for the frequency of reciprocity is rate-limited by human participants. This brings the rate more in line with familiar human-human interaction. Reeves and Nass (1996) presented evidence from scores of empirical studies demonstrating that people treat media like people in spite of a cognitive understanding that they are not human participants. They argued that the mammalian brain has not evolved to react to human-like activity in inanimate objects. The scale and varied forms of digital information objects support many such cycles in an information-seeking and use session. Shneiderman (1994) notion of dynamic queries illustrated how simple physical actions such as moving the mouse can pose queries that generate feedback in fractions of a second, allowing hundreds of queries per minute. The bottleneck thus becomes the human's digesting the feedback. In dynamic query systems, this is presumably facilitated by highly organized visual display. Using today's faceted browsing systems and dynamic query interface mechanisms, people are able to execute scores of interaction cycles in large databases (e.g., eBay or Amazon catalogs) in very short intervals.

Changes in the human–information interaction entities relate to learning or other mental state changes in the human and usage changes in the information object. Log files record part of the history of an information object. These files have traditionally been used for billing and error diagnosis purposes; however, researchers also study them to understand patterns of use across populations. For example, Spink and Jansen (e.g., Jansen, Spink, & Pedersen, 2005) conducted a number of analyses of search engine query logs to characterize typical search interests and, by inference, behavior. Kelly (2006a, 2006b) used a more naturalistic approach to study search activity by instrumenting participants' laptops to collect client-side activity over a semester. Increasingly, the logs of sequences of interactions, known as click streams, are used as the basis for actively influencing the instantaneous acts of information objects. White, Bilenko, and Cucerzan (2007) used large amounts of such streams to discover predictive models for popular Web destinations and how these might in turn be used to influence search queries. Today's search engines use spatial (e.g., geographic information from IP addresses) and temporal information in the human action (e.g., query statement, mouse click) to make on-the-fly changes in what is displayed (the feedback). AJAX techniques allow information objects to be assembled on the fly depending on a variety of conditions. This allows information objects that are static (e.g., a PDF file) to admit annotations and contextualizing information and, more importantly, allows customized content to be assembled while taking into account a large variety of personal and global conditions. Thus, information entities change according to individual and collective interactions over time.

More subtly, the click streams of others can be used to change the feedback (recommendation systems) or place customized ads on the feedback. User profiles can be created based on interaction patterns over time or based on explicit feedback in specific interaction cycles. Recent work by Fu (2007) used screen capturing and eye tracking to demonstrate how reference librarians observing search behaviors can interpret very subtle activities by searchers (e.g., moving the mouse, modifying queries and skipping results). As researchers capture and analyze more searcher behavior, they will surely incorporate such observations into automated techniques to characterize searchers and customize interaction feedback.

7. Human–information interaction implications and discussion

The evolution of digital information objects and new conceptions of human intentionality and behavior make human–information interaction a core phenomenon for the information field. Human–information interaction shifts the foci of all aspects of information work; blurs boundaries between information objects, technology, and people; and creates new forms of information, such as identity proflections. Information researchers and practitioners are increasingly finding that they must study and manage information experiences as much as physical objects. Understanding and facilitating information interaction requires considering the process of interaction, as well as the resultant changes in both the human–information seeker and the information objects. This, in turn, requires new methods and tools of investigation. These methods range from quantitative studies of massive amounts of behavioral data to in-depth ethnographic studies over long periods of time.

8. New roles for information professionals

Information professionals face rapid changes in key functionalities. Librarians concerned with collection development, classification and cataloging, and reference services face fundamental challenges to their day-to-day activities. Rather than acquiring physical objects, they are increasingly acquiring licenses for databases and services that are not physically housed in their collections. They find themselves selecting and acquiring an expansive range of information products, from physical books and DVDs to games and the various devices necessary to interact with new forms of information.[9] In addition to the classical tools for indentifying and selecting materials, they are learning about automatic harvesting systems to augment their digital collections (e.g., Bergmark, 2002).[10]

Cataloging was revolutionized in the twentieth century by shared cataloging services such as OCLC. Two current developments have arisen to help information professionals meet the new challenges of cataloging massive numbers of fluid, Web-based resources: social tagging and machine learning algorithms. The enormously popular success of allowing information creators and consumers to add free-text labels (tags) to webpages (e.g., del.icio.us) and images (e.g., Flickr) have raised social tagging as a serious solution for library collections, at least for topical descriptions (Morville, 2005). The debate about allowing open tagging raises basic questions about the nature of authority and expertise more generally. Even the Library of Congress, bastion of controlled vocabulary, has begun to investigate hybrid solutions that combine professional and patron descriptions.[11] An important component of managing access to information objects is creating metadata that serves as identifiers for retrieval and that also serve as gisting cues (surrogates) for relevance assessment. The challenges of creating surrogates for multimedia objects led to a variety of non-textual representations for information objects. The Open Video Project has endeavored for more than a decade to create

[9] In early 2008, more than 20 public libraries were included on a Wii libraries wiki at http://www.libsuccess.org/index.php?title=Wii_Libraries

[10] The author's research group is developing strategies and tools to assist curators in harvesting contextualizing video assets for their collections (http://www.ils.unc.edu/vidarch).

[11] See http://www.loc.gov/bibliographic-future/news/lcwg-ontherecord-jan08-final.pdf for report of a blue ribbon panel report on future of bibliographic control that envisions a Web-based, collaborative, decentralized approach to cataloging and classification.

highly compact visual and audio surrogates for videos that allow people to augment textual descriptions with media summaries to judge in a minute or less whether to watch full videos in real time. Concurrent with facing the possibilities (scalability) and problems (reliability) of social tagging to deal with the challenges of scalable description, researchers have developed powerful machine learning techniques to classify Web-based objects. Their ultimate vision is the semantic Web (Berners-Lee, Hendler, & Lassila, 2001). Increasingly, librarians will use data-mining techniques as often as they used to use book reviews and cataloging rules to develop and provide access to collections. These techniques have improved to the point where a good amount of the cataloging can be done automatically. Much more can be done mainly by machines with human supervision, thus freeing human catalogers to cope with the most important, novel, and complex information objects.

Reference services have likewise begun to adapt to new forms of information and the ways that people interact with information objects. Remote (virtual) reference services (Lankes, Westbrook, Nicholson, Radford, & Silverstein, 2007) have become the norm in academic and many public libraries. Chat, instant messaging, and email are the typical channels and new environments such as Second Life are under trial.[12] Such services not only change the *how* of reference, but also the *who* in that the service population can quickly become global if some kind of library card identification is not required. Many sources used to answer reference questions have also migrated to the Web, which makes service-specific search tactics less important and general Web search strategies more important. Thus far, automatic question-answering systems[13] have not been good enough to augment library reference, although reference librarians are wise to monitor progress and adopt successful techniques. Finally, the role of reference has shifted from referral and question-answering to training and problem solving. The emphasis is on helping patrons interact with information.

Just as the work of librarians is evolving, so is the work of information professionals such as information technology specialists in offices and laboratories everywhere. The evolution of information technology support from hardware to software and now to services is well documented in the information technology literature. For example, Cusumano (2008) describes how major software corporations have evolved to be service providers. IBM has initiated a services science research and development (R&D) effort (Chesbrough & Spohrer, 2006) that aims to feed its transformation to a global services company. Information technology professionals thus find themselves doing more training, business-oriented problem solving, and researching licenses and upgrade paths, just like librarians. The emphasis has shifted from the tools themselves (hardware, software) to people's needs and experiences meeting those needs.

9. New forms of information

Digital technology has created a plethora of new kinds of information objects, including multimedia combinations that exhibit behavior, acquire history over time, and lead to new emergent properties. When these objects are Web-based, they acquire a scalability feature that leads to new kinds of emergence: interactions among millions of people and trillions of machine cycles create new kinds of information objects defined by instantaneous states of the network.

One new kind of information object with consequences for individuals is one's identity in cyberspace. Humans consciously project their identity through personal Web pages, social networking profiles, email signatures, and other purposeful interactions with electronic environments (collectively called “cyberspace”). Additionally, humans working in electronic environments unconsciously leak information through their behavior patterns (e.g., query histories, spam filter settings, and hyperlink click patterns), a form of exoinformation (Brunk, 2001). Taken together, these conscious and unconscious *projections* make up our virtual identities, which in turn can be leveraged in various ways by ourselves, by others, and by automated processes. Some people use projections to promote ideas and attract attention; others use them with a variety of intentions to find other people. In addition to what we project about ourselves, the nature of cyberspace allows other people to annotate, cite, and link to our projections, creating embellished identities. For example, people link to others' Web pages, comment on blog or social network postings, or forward email messages. People may be aware of some of these embellishments, but most are not known. More importantly, machines work continually to observe our projections and embellish them for a variety of purposes. These purposes range from providing help or making recommendations to influencing purchases or stealing our resources. They are reflections of our identity. Taken together with the projections, they form a new kind of information called proflections of identity. Proflections are an example of information objects and processes that are distributed, may not ever be fully discernable at any given time, and continue to evolve. They are the traces of our interactions with people and information objects. They have value to our lives and demonstrate the importance that information interaction plays in all aspects of twenty-first century life. Understanding how proflections form and evolve and discovering ways to manage them provide exciting new challenges to the information field. Similar challenges occur when studying the traces of interactions in social networks and global commerce.

10. Research challenges

Proflections are but one new kind of information that information researchers and practitioners must consider. The state of the Web at any instant represents a snapshot of both public human knowledge[14] and social cognition. The Internet Archive (http://archive.org) aims to capture these states periodically and preserve them for posterity. However, at present the emphasis is on the static components of the Web. Likewise, various current book digitization projects[15] will make the world's published knowledge searchable and accessible. In both cases, new research and development challenges range from technical issues of storage and indexing to social issues of property rights and costs. It is reasonable to expect that such knowledge should be equitably accessible worldwide, but it is crucial that the tools for access and analysis also be available. People with access to structured text have definite advantages over those with access to unstructured text; people and institutions with powerful text analysis and data-mining tools have definite advantages over those without such tools and expertise. Information scientists will lead the efforts to collect and make this knowledge available and will create the tools and techniques for access and analysis. People who know good strategies for interacting with information have definite advantages over those who flounder in a sea of fluid information resources Information scientists must continue to lead the study of the interactions between people, information objects, and tools that define these knowledge repositories. Information scientists must discover new strategies and tools for human–information interaction and teach people how to optimize their efforts.

[12] See the December/January 2008 issue of Bulletin of ASIST for a series of articles on virtual reference.

[13] There is a question-answering track in the TREC conferences, demonstrating the considerable research activity underway.

[14] There is much more information contained in non-public electronic forums.

[15] The Universal Digital Library Million Book Project (http://www.ulib.org/), the Open Content Alliance (http://www.opencontentalliance.org/), and the Google Book Project (http://books.google.com/googlebooks/library.html) are digitizing millions of books each.

Although the state of public human knowledge may be captured, global information activity is more difficult to capture. Instantaneous data such as the queries generated on a given day to all the different search engines, the ranking of a specific page or posting over time, or the number of clicks on all the pages related to a specific topic characterize a state of humanity's distributed cognition. Access to the states of these billions of actions provides researchers with a glimpse of what humanity is thinking. This has exciting new possibilities for understanding human behavior and the human condition more generally. At this point, only the largest Web companies have enough data and resources to begin to monitor and study the flow of human behavior in cyberspace. A major challenge for information scientists is to develop techniques and tools to study human–information interaction from a social perspective. Whether the tools and techniques developed to study individual behaviors will scale to large-group or global settings remains to be seen.

More specifically, information scientists must develop ways to examine human–information interaction as a whole process that is greater than the sum of the information/people/technology parts. This requires new tools to observe changes over time—changes in information objects as they morph based on internal or external conditions, changes in people as they learn and adapt behaviors, and changes in the technologies that become increasingly transparent but intrinsically a part of the information objects. Humans will live and work in a hybrid physical and digital world. They will study how people transition between these worlds, as well as the effects of those transitions. Beyond helping people cope with information overload, information scientists must develop ways to study how information is used, reused, and aggregated. Maintaining a record of bit creation, transfer, and use[16] would require more resources than practical; thus issues of bit ownership will continue to challenge us for the foreseeable future. Clearly, the research challenges of human–information interaction are just beginning to be recognized.

11. Conclusion

The importance of human–information interaction is illustrated by the number of research papers that use the term,[17] its appearance in course titles and curriculum threads, and centers of research devoted to its study.[18] There is a strong shift in the HCI community toward focusing on interaction with information rather than computers. For example, one of the long-standing leading laboratories in HCI, Xerox PARC, now uses the term human–information interaction. Toms (2002) used information interaction as the underlying framework for information architecture. Scholtz (2006) provided an HCI perspective on methods and metrics for studying human–information interaction. Recognizing that search engine services are satisfying basic retrieval needs for Web-based information objects, the information retrieval community has begun to shift more attention to how people interact with information throughout search sessions, in collaboration, and across sessions. Workshops, papers, and research groups have evolved around topics such as exploratory search, collaborative search, and interactive information retrieval. Both the HCI and IR communities are also augmenting their traditional respective models of human-machine and query-document interactions; they include social components that take into account past and current explicit or implicit relationships across information objects that are based on human interactions with those objects. In essence, people are changing what they do with information—they no longer only consume it (read/view/listen/ponder) but they annotate, link, and extend it as they consume—i.e., they interact with it. Furthermore, these interactions themselves yield traces that change us, information objects, and the state of cyberspace. These developments make it an exciting time for the information field. It is maturing as a discipline while opening up new areas for research that have theoretical and practical relevance to the human condition.

Radical changes in the nature of information due to electronic technologies are enabling substantial human–information interactions. The combination of malleability and conditionality possible through programming, world-wide instant communication linkages, and practical mass storage make information in electronic form a first-class actor in human–information interactions. The fact that information objects can present many fixed or randomly generated states gives them a kind of dynamism only exhibited by animals throughout human history. Surely digital objects will stand alongside traditional information objects in a diverse information space where people interact with each other and those objects using the support of information professionals and services. These developments require that people take a more ecological view of information and develop new kinds of methods and perspectives for research and practice.

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References

Bates, M. (1989). The design of browsing and berrypicking techniques for the online search interface. *Online Review*, *13*, 407–424.

Belkin, N., Oddy, R., & Brooks, H. (1982). ASK for information retrieval: Part 1: Background and theory. *Journal of Documentation*, *38*(2), 61–71.

Bergmark, D. (2002). Collection synthesis. *In Proceedings of the 2nd ACM/IEEE-CS Joint Conference on Digital Libraries* (pp. 253–262) New York: ACM.

Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The semantic Web: Computers navigating tomorrow's Web will understand more of what's going on – making it more likely that you'll get what you really want. *Scientific American*, *284*(5), 34–43.

Blake, C., & Pratt, W. (2006). Collaborative information synthesis I: A model of information behaviors of scientists in medicine and public health. *Journal of the American Society for Information Science and Technology*, *57*, 1740–1749.

Bolter, J. D. (1991). *Writing space: The computer, hypertext, and the history of writing.* Hillsdale, NJ: Lawrence Erlbaum.

Brown, J. S., Collins, A., & Duguid, S. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Bruce, H., Fidel, R., Pejtersen, A. M., Dumais, S. T., Grudin, J., & Poltrock, S. (2003). A comparison of the collaborative information retrieval behaviour of two design teams. *New Review of Information Behaviour Research*, *4*(1), 139–153.

Brunk, B. (2001). Exoinformation & interface design. *Bulletin of the American Society Information Science and Technology*, *27*(6), 11–13.

Buckland, M. (1991). Information as thing. *Journal of the American Society for Information Science*, *42*(5), 351–360.

Card, S., Moran, T., & Newell, A. (1983). *The psychology of human-computer interaction.* Hillsdale, NJ: Lawrence Erlbaum.

Chesbrough, H., & Spohrer, J. (2006). A research manifesto for services science. *Communications of the ACM*, *49*(7), 35–40.

Clark, A. (1997). *Being there: Putting brain, body, and world together again.* Cambridge, MA: MIT Press.

Cuadra Associates. (1982). A library and information science research agenda for the 1980s: Summary report. *Library Research*, *4*, 235–277.

Cusumano, M. (2008). The changing software business: Moving from products to services. *Computer*, *41*(1), 20–27.

Fidel, R., & Pejtersen, A. M. (2004). From information behavior research to the design of information systems: The cognitive work analysis framework. *Information Research: An International Electronic Journal*, *10*(1). Retrieved March 10, 2008, from http://informationr.net/ir/10–1/paper210.html

Fu, X. (2007). *Evaluating sources of implicit feedback for Web search.* Unpublished doctoral dissertation, University of North Carolina at Chapel Hill.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA: MIT Press.

Ingwersen, P., & Järvelin, K. (2005). *The turn: Integration of information seeking and retrieval in context.* New York: Springer-Verlag.

Jansen, B. J., Spink, A., & Pedersen, J. (2005). A temporal comparison of Alta Vista Web searching. *Journal of the American Society for Information Science and Technology*, *56*, 559–570.

[16] A singular signature for each bit created (a kind of radioisotope attached to everything created) is an ultimate killer application; the increasing use of plagiarism detection software is a more practical indication of this problem at the document level.

[17] As of February, 2008 the LISA database returned 111 papers with information interaction somewhere in the full bibliographic record.

[18] For example, the Center for Human Information Interaction at the University of Washington: http://projects.ischool.washington.edu/chii/

Johnson, M. (1987). *The body in the mind.* Chicago: University of Chicago Press.

Johnson, M. (2007). *The meaning of the body: Aesthetics of human understanding.* Chicago: University of Chicago Press.

Johnson-Laird, P. N. (1983). *Mental models: Toward a cognitive science of language, inference and consciousness.* Cambridge, MA: Harvard University Press.

Kelly, D. (2006a). Measuring online information-seeking context, Part 1. Background and method. *Journal of the American Society for Information Science and Technology*, *57*, 1729−1739.

Kelly, D. (2006b). Measuring online information-seeking context, Part 2. Findings and discussion. *Journal of the American Society for Information Science and Technology*, *57*, 1862−1874.

Kuhlthau, C. (1988). Longitudinal case studies of the information search process of users in libraries. *Library and Information Science Research*, *10*, 257−304.

Lankes, D., Westbrook, L., Nicholson, S., Radford, M., & Silverstein, J. (Eds.). (2007). *Virtual reference service: From competencies to assessment.* New York: Neal-Schuman.

Mani, I., & Maybury, M. (1999). *Advances in automatic text summarization.* Cambridge, MA: MIT Press.

Marchionini, G. (1995). *Information seeking in electronic environments.* New York: Cambridge University Press.

Marchionini, G. (2006, June/July). Toward human-computer information retrieval. *Bulletin of the American Society for Information Science and Technology,* 32(5).

Marchionini, G., Geisler, G., & Brunk, B. (2000). Agileviews: A human-centered framework for interfaces to information spaces. In D. Kraft (Ed.), *Proceedings of the 63rd Annual Meeting of the American Society for Information Science and Technology* (pp. 271−280). Silver Spring, MD: ASIST.

Miller, P. (2004). *Rhythm science.* Cambridge, MA: MIT Press.

Mitchell, W. J. (2003). *Me++: The cyborg self and the networked city.* Cambridge, MA: MIT Press.

Morris, M. R., & Horvitz, E. (2007). Searchtogether: An interface for collaborative web search. *In Proceedings of UIST '07* (pp. 3–10). New York: ACM.

Morville, P. (2005). *Ambient findability.* Sebastapol, CA: O'Reilly.

Newell, A., & Simon, H. A. (1972). *Human problem solving.* Englewood Cliffs, NJ: Prentice-Hall.

Oblinger, D., & Oblinger, J. (Eds.). (1996). *Educating the net generation.* Washington, DC: Educause. Retrieved March 10, 2008, from http://www.educause.edu/content.asp?PAGE_ID=5989&bhcp=1

Reeves, B., & Nass, C. (1996). *The media equation: How people treat computers, television, and new media like real people and places.* New York: Cambridge University Press.

Saracevic, T., & Kantor, P. (1988). A study of information seeking and retrieving. III. Searchers, searches and overlap. *Journal of the American Society for Information Science*, *39*, 197−216.

Shneiderman, B. (1983). Direct manipulation: A step beyond programming languages. *IEEE Computer*, *16*(8), 57−69.

Shneiderman, B. (1994). Dynamic queries for visual information seeking. *IEEE Software*, *11*(6), 70−77.

Scholtz, J. (2006). Metrics for evaluating human information interaction systems. *Interacting with Computers*, *18*, 507−527.

Stotts, P. D., Furuta, R., & Cabarrus, C. R. (1998). Hyperdocuments as automata: Verification of trace-based browsing properties by model checking. *ACM Transactions on Information Systems*, *16*(1), 1−30.

Toms, E. (2002). Information interaction: Providing a framework for information architecture. *Journal of the American Society for Information Science and Technology*, *53*, 855−862.

Trigg, R. H., & Weiser, M. (1986). TEXTNET: A network-based approach to text handling. *ACM Transactions on Information Systems*, *4*(1), 1−23.

Weiser, M., & Brown, J. S. (1995). *Designing calm technology*. Retrieved March 10, 2008, from http://www.ubiq.com/hypertext/weiser/calmtech/calmtech.htm

Wellisch, H. (1972). From information science to informatics: A terminological investigation. *Journal of Librarianship*, *4*(3), 157−187.

White, R. W., Bilenko, M., & Cucerzan, S. (2007). Studying the use of popular destinations to enhance web search interaction. In W. Kraaij, A. P. de Vries, C. L. A. Clarke, N. Fuhr, & N. Kando (Eds.), *SIGIR 2007: Proceedings of the 30th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Amsterdam, The Netherlands, July 23-27, 2007* (pp. 159−166). New York: ACM.

Zellweger, P. T. (1989). Scripted documents: A hypermedia path mechanism. *In Proceedings of the Second Annual ACM Conference on Hypertext* (pp. 1–14). New York: ACM.