Chapter 3. Information-Seeking Perspective and Framework

The whole of science is nothing more than a refinement of everyday thinking. (Albert Einstein, Physics and Reality)

Information seeking involves a number of personal and environmental factors and processes. In this chapter we will identify these factors and processes and see how they work together to define and constrain information seeking. Before reading further, stop and consider the many information-seeking activities you perform each day. Suppose you have a well-defined information need such as finding a phone number for a business in a foreign city. What do you need to know to begin? What things do you already know about telephones, businesses, and information seeking that will help in your search? What sources may possibly help? How do you determine if they are available? How do you use them? What are the costs in time or money? How do you know when you have found the correct number? What kinds of questions can you imagine for a more open-ended but well-focused information problem such as understanding the implications of the European Common Market's trade agreement with Japan on what investments to make for a child's college trust fund? How would your strategies differ for a fuzzy problem like gaining knowledge to improve one's knowledge of a domain of interest? Clearly, we encounter many varieties of information problems and apply varied information-seeking strategies to solve these problems. To understand this variety, it is useful to have a framework that explicates factors and processes common to information seeking in general.

INFORMATION-SEEKING PERSPECTIVE

The perspective on information seeking taken in this book has its roots in the work of scholars in information science, psychology, education, communications, and computer science. The perspective emerges from three beliefs about human existence: life is active, analog, and accumulative. The active view of life implies that we learn by "bumping into the environment." This experiential and biological view has been expressed in the learning philosophy of John Dewey and the psychological theory of Jean Piaget respectively. Our actions may be classified as reactive or proactive. Reactions require perceptive inputs of information and relatively rapid recall of information from memory. We perceive the situation at hand through our senses and determine our reactions according to existing mental models. Proactions are guided by plans, employ outputs of information (e.g., trial balloons), active information gathering (e.g., hypothesis testing), and require synthesis of information. The balance between reactive and proactive actions is determined by individual characteristics such as age or experience, and by the stability and organization of the environment. Thus, highly organized social and political environments allow those who have experience to manipulate more information in imaginative and reflective ways to plan their actions. The information society and its highly organized work environments demand highly developed personal information infrastructures to guide our many intellectual and physical actions.

Life as an analog process means that it is continuous and periodic. The continuity of individual lives implies that information incessantly flows from the environment regardless of how we are able to process and store it. This continuity causes us to develop mental and physical apertures as part of our personal information infrastructures so that we can control information flow. Periodicity describes the "ups and downs" of our physiological, psychological and spiritual lives. These periods are both internally determined and influenced by the environment, and they affect our abilities to seek, accept, and process information.

Life as accumulation is a corollary of continuity in that it is difficult or impossible for us to selectively and purposefully forget the effects of information we have processed in our life. As information affects our knowledge structures, these structures are extended, reinforced, or altered. This accretional process not only broadens our understanding of the world, but also bolsters our biases and affects our subsequent expectations. This belief implies that organization of our information resources is critical to effective future actions and that we must not only control the amount of information, but also must develop evaluative filters to minimize inaccurate or low-quality information.

Life requires us to plan and execute actions (actions can be mental activities as well as physical). To do so, we need to have plausible mental models (understandings) of the world. To have such mental models, we need information--anything with the potential to change a mental state (Belkin, 1978). Thus, information seeking is a process driven by life itself. More specifically, information seeking is a process driven by human needs for information so that they may interact with the environment.

This view of information seeking has paralleled developments in our thinking about psychology, sociology, and technology. Rather than focusing exclusively on the representation, storage, and systematic retrieval of information, or on information systems, the current view of information seeking places strong emphasis on communication, and the needs, characteristics, and actions of information seekers (Dervin & Nilan, 1986). This focus parallels the development of cognitive psychology which goes beyond the stimulus-response (input-output) constraints of behavioral psychology to examine human cognitive processes. It has been reinforced by developments in communications and computing technology and their attendant problems related to acceptance, behavioral changes, and potential abuse. As discussed in the previous chapter, these developments have led to increased interactions among people and systems.

Human-centered models of information seeking.

Attention to users of information systems and consideration of their needs from a communications perspective is well-represented in the literature. Dervin (1977) has been particularly influential in focusing attention on user needs by virtue of her model based on people's needs to make sense of the world. The model posits that users go through three phases in making sense of the world, i.e., facing and solving their information problems. The first phase establishes the context for the information need, called the situation. Given a situation, people find that there is a gap between what they understand and what they need to make sense of the current situation. These gaps are manifested by questions. The answers or hypotheses for these gaps are then put to use to move to the next situation. This situation-gap-use model applies to more general human conditions than information seeking, but has been adopted by researchers in information science and communications as a framework for studying the information-seeking process.

Belkin and his colleagues (Belkin, 1980; Belkin, Oddy, & Brooks, 1982) have developed a model of information seeking that focuses on information seekers' anomalous states of knowledge (ASK). In this model, information seekers are concerned with a problem but the problem itself and the information needed to solve the problem are not clearly understood. Information seekers must go through a process of clarification to articulate a search request, with the obvious implication that search systems should support iterative and interactive dialogues with users. This model was designed to explain generally open-ended information problems and does not directly apply to fact-retrieval type problems or to accretional information seeking done by experts in a field. The ASK model serves as a theoretical basis for the design of information systems that are highly interactive.

In a much more specific context, Kuhlthau (1988) has developed a model of how students search for information as part of the writing process. Her model takes both cognitive and affective perspectives and was developed through observations and interviews with students over extended periods of time. The model crosses feelings, thoughts, and actions with seven stages: task initiation, topic selection, prefocus exploration, focus formulation, information collection, search closure, and starting writing. The model is robust across different age groups of learners (Kuhlthau, Turock, George, & Belvin, 1990) and addresses the affective states of information seekers.

These and other models of information-seeking behavior share perspectives on information seeking as a problem-solving activity that depends on communication acts. This perspective is accepted by researchers and practitioners in information science but has only begun to influence designers and engineers who implement electronic retrieval systems. Since this perspective does parallel the user-centered philosophy prevalent in human-computer interaction research, it is likely that electronic retrieval systems will eventually exhibit interfaces that support active, problem-oriented information seeking. The perspective shared by these models is also the basis for the framework developed in this chapter. Before describing the components of the framework and the processes associated with them, it is useful to consider an overview of three types of user studies that motivate and provide examples for this framework.

Studies of users of electronic retrieval systems.
A number of researchers have studied people using electronic retrieval systems in order to characterize the search process from a user perspective. These studies have focused on professional intermediaries who regularly use a system or on "end users" who may be novices or occasional users of the system. Often, these studies have been conducted on existing systems with design specifications that are typically information-centered or system-centered rather than user-centered. Some more recent studies have taken the approach of formative evaluation done in conjunction with actual system development. A few of these investigations are described here to illustrate the many factors that make up the information seeking framework[1]. This overview is meant to provide a context for the framework and user studies will be considered in detail in light of the framework in subsequent chapters.

Fidel's work with professional online searchers typifies studies of expert intermediaries (Fidel, 1984). She conducted intensive case studies of intermediaries conducting searches of online bibliographic databases. Based on her observations and interviews, she defined two searching styles: operationalist and conceptualist. An operationalist searcher devotes considerable effort to manipulating the system and conducts high-precision searches. A conceptualist searcher devotes more effort to the concepts and terminology and tends to develop subsets of results that are then combined in various ways to yield high recall[2]. This work has been extended to address particular aspects of searching such as how subject terms are selected and used by professional searchers in a variety of fields (Fidel, 1991).

Saracevic and his colleagues (1988a, 1988b, 1988c) conducted the largest study to date of online searching by expert intermediaries using a framework of five variable classes: users, questions, searchers, searches, and items retrieved. Their findings indicate that end-user variables have little effect on outcomes as measured by the odds of retrieved documents being at least partially relevant, and that recall and precision values were generally consistent across variables. Exceptions include: well-defined problems increased relevance odds, estimates of public knowledge (the end-user's expectations about what information is available in the system) increased relevance and precision odds, and user-defined limits on language and currency of documents increased relevance and precision odds. Various cognitive characteristics of searchers had mixed effects on their performance, with preference for abstractness over concreteness having significant positive effects on relevance and recall odds. Term selection overlap among intermediaries was low, as was overlap among retrieved document sets--reinforcing the view of online retrieval as more an art than a science. The studies reported many other results related to how searches were executed and what types of outcomes were obtained, but a key recommendation was to investigate the complex nature of the search process in context as well as in laboratory settings. In addition to the extensive portrait these studies provide for intermediaries searching electronic databases, the framework for question classification and the application of quantitative and qualitative evaluation measures make these efforts seminal in the field.

Studies of end users are typified Borgman's investigations of the cognitive activity of college students and children using various bibliographic databases (Borgman, 1986, Borgman, 1990). She applied the psychological theory of mental models to explain learning and errors and made a case for instructional approaches that are conceptual in nature rather than simply procedural. Her systematic user studies also provide the basis for continued development and redesign of an online catalog customized for elementary students (Borgman, Gallagher, Krieger, & Bower, 1990). Borgman's early work was the basis for some of the studies Marchionini conducted with K-12 students searching full-text electronic encyclopedias (Marchionini, 1989a; 1989b). In his work, elementary school children were able to use the electronic environment successfully to conduct searches for simple subjects, and high school students were found to exhibit difficulties with complex queries and to develop mental models for the new system based on print metaphors and individual information-seeking skills and characteristics.

In some cases, studies of end users were part of overall development efforts for specific electronic retrieval systems. Formative evaluation examines how users interact with system prototypes to inform the iterative design process. Egan, Remde, Gomez, Landauer, Eberhardt, & Lochbaum (1989) studied users of their SuperBook hypertext system and used results in making substantial improvements in subsequent versions of the system. Marchionini and Shneiderman (1988) likewise used the results of user studies for subsequent versions of the Hyperties hypertext system and various Hyperties databases. Ongoing end-user evaluations of the Perseus Project system have also influenced subsequent releases of this hypermedia corpus (Marchionini & Crane, 1994). Generalizable results from these studies illustrate the usefulness of highlighted query terms, use of tables of contents to provide content for users, and high acceptance by users of interactive browsing.

A substantial number of studies of end users have been focused on online public access catalogs in libraries. Early studies sponsored by the Council on Library Resources led to better understanding of the types of searches users conducted (e.g., over half of all OPAC searches were subject searches rather than title or author) and identified the wide range of results users obtained (e.g., about 10% of commands resulted in errors, except in the menu interface of MELVYL where 2% error rates were found) (Larson, 1983; Markey, 1984; Matthews, 1982). Studies of user error patterns (Janosky et al, 1986) highlighted not only the interface defects of OPACs, but also that casual users have poor understandings of libraries in general and exhibit naive and careless actions while searching. These results are cited as influential in the improved designs for second generation OPACs (Hildreth, 1989; Larson, 1991)

In sum, studies of how users apply electronic retrieval systems to information-seeking problems have yielded results that reinforce the general theory of user-centered information seeking that focuses on highly active users with a broad range of information problems. They also illustrate the importance of task and system parameters. These results have spawned new designs for retrieval systems and demonstrated the value of user testing and iterative design. More importantly, they have reinforced and extended the perspective of information seeking as a human-centered problem-solving activity.

FACTORS OF INFORMATION SEEKING

Information seeking depends on interactions among several factors: information seeker, task, search system, domain, setting, and search outcomes. (Marchionini & Shneiderman, 1988; Marchionini, 1989c). Figure 2.1. depicts these factors and the relationships that bind them. The setting is the situational and physical context for information seeking. The information seeker is central to the framework and exploits the factors as information seeking progresses. The information seeker is motivated by an information problem or need that activates a variety of noumena--mental images or memory traces. These fuzzy notions and the relationships among them form concepts that define the problem and are in turn articulated as a task (e.g., a verbal statement of the problem or a set of purposeful actions related to solving it. The search system is the source of information and the rules for access. Search systems are selected by the information seeker or made available by the setting as a default. Domains are fields of knowledge (e.g., chemistry, medicine, and anatomy may be activated in a health situation) and traces of the overall process. Outcomes are the feedback from the system (e.g, document surrogates, images, system messages, etc.). Information seekers reflect on outcomes and this reflection in turn changes the knowledge state and determines whether to continue or terminate information seeking.

[Figure 3.1. about here]

All the factors are embedded in a setting; the domain and search system are interrelated; the information seeker perceives and interprets the setting, has mental models for the domain(s) and the search system, and turns an information problem into a task that drives his/her interactions with the search system; these interactions yield outcomes that in turn affect the information seeker and the problem. These factors are discussed in detail in the following sections.

Information seeker.

This framework for information seeking is human-centered in that the information seeker defines the task, controls interaction with the search system, examines and extracts relevant information, assesses progress, and determines when the information-seeking process is complete. Each information seeker is unique, possessing particular mental models, experiences, abilities, and preferences. Experience with particular settings, domains, and systems generally allow more comprehensive and accurate mental models and thus more facility with these models. The information seeker's personal information infrastructure affects overall performance while solving information problems and executing tasks, and continues to develop as information seekers accrue experience and knowledge. With every information problem, information seekers reinforce and extend their mental models for the various factors and subprocesses associated with information seeking.

Professional intermediaries who regularly conduct searches for others are familiar with many sources of information (search systems) and are able to apply various information-seeking strategies. They demonstrate expertise in information seeking through their knowledge of different search systems and strategies for assisting people in articulating tasks. Experts in a field of study have comprehensive vocabularies in the domain, know what types of sources are best applicable to problems, and are aware of alternative access points for finding information in the domain (e.g., personal, corporate, geographic, etc.). Our studies of professional intermediaries and domain experts in computer science, economics and law suggest that although both types of experts have significant advantages over novices when conducting searches, each type of expert also exhibits specific advantages with respect to one another (Marchionini, Lin, & Dwiggins, 1990; Marchionini, Dwiggins, Katz, & Lin, 1993). Intermediaries focus on the information task as expressed in the question, on query formulation, and on the interface aspects of the system (e.g., structure of information), and are generally guided by matching questions to database structure. Domain experts seem to be have an image of the answer and are guided by identifying possible answers in the database. Domain experts spend more time in scanning and reading text and less time formulating and modifying queries. Regardless of the specific advantages either type of experts have, expertise clearly affects information seeking, just as it does other intellectual efforts such as chess (Newell & Simon, 1972) or medical decision making (Spiro et al, 1989). The nature of expertise and its role in information seeking will be examined in detail in the next chapter.

Individual differences among information seekers play a role in both specific instances of information seeking and in the overall development of personal information infrastructures. Egan (1988) has identified age and spatial reasoning as important factors in a variety of task performance areas, including, information seeking. Other researchers have studied cognitive style (e.g. Bellardo, 1985), and personal variables such as academic success, reading ability, field of study, and verbal and quantitative abilities to determine their relationships to information seeking (e.g, Borgman, 1989;

Marchionini, 1989c). Because these individual differences are not independent, no single characteristic will alone predict information-seeking performance. However, cognitive, physical, and emotional differences between and within individuals influence specific behaviors and general affinities and abilities.

In addition to individual differences, it is important to consider that information seeking is part of an individual's ongoing effort to understand and act in the world. Each individual is situated in a context at any given instant that influences all actions, including information seeking (see Suchman, 1987 for a theory of situated human activity applied to human-machine interactions). Situational personal variables such as physical, cognitive and emotional health affect human performance and cannot be ignored. Even more slippery is the motivation to initiate and continue information seeking. Motivation to initiate search may be driven by external or internal needs but the tenacity to continue search may depend on personality factors such as perseverance and on external factors such as time and money.

The most basic situational factor for information seeking, however, is the information problem that irritates the user to action. Taylor (1962) defined four levels of information needs: visceral, conscious, formalized, and compromised. The visceral level is recognition of some deficiency, but not cognitively defined. At the conscious level, the information seeker characterizes the deficiency, places limits on it, and is able to express the problem, albeit with ambiguity. At the formalized level, the person is able to articulate clear statements of the problem (e.g., in English), and the compromised level refers to the formalized statement as presented in a form constrained by search system limitations (e.g., in a database query language). The conscious and formalized levels correspond to the task in the framework presented here.

Taylor's visceral and conscious levels of information need correspond to what Dervin called a "gap", and what Belkin and his colleagues refer to as an “anomalous state of knowledge”. Using a computational metaphor, Marchionini (1989a) has characterized the information problem as emerging from a defect in one's mental model for some idea, event or object. This state initiates search in long-term memory and if the defect cannot be mended (either correctly or through rationalized guessing), then information seeking is initiated by activating the personal information infrastructure and passing the contextual parameters to it. He defined the personal information infrastructure procedure by observing how people used manual and electronic encyclopedias and noted a significant difference in the electronic instantiations in that those systems often returned large sets of articles as outcomes rather than a single article or small set of “see also” articles in the manual case. By automatically involving the index in search, these electronic systems required additional explicit decision-making steps on the part of users. This approach was useful in formulating the human-system interaction phases of the information-seeking process but mental model structures seemed ill-suited to information needs since they are elaborate and take time to develop.

To address this deficiency, consider the knowledge state of an information seeker at some instant as a collection of noumenal clouds. Each noumenal cloud is a fuzzy image composed of noumena (memory traces and impressions) that have the potential for being related together as a concept or idea. These clouds are highly fluid; the noumena within a cloud come and go as thought progresses, as do the clouds themselves. A knowledge state consists of several noumenal clouds that are related by common noumena--analogous to valence bonds between atoms in a molecule. The knowledge state is well defined when the noumena within clouds are stable and the clouds have many noumena in common. In this case, new clouds are not formed and active clouds remain active--there is relative certainty in the knowledge state. An information problem is a collection of noumenal clouds that is unstable; clouds come and go because there are not enough stable common noumena. In this case, the knowledge state has a high degree of uncertainty in definition of noumena and clouds and thus a high potential for state change, i.e., acquiring information. In the most common cases, greater numbers of noumena are needed for stabilization (simply activating more memory traces to define a cloud). In more complex cases, overlaps of noumena across clouds are needed for stabilization.

Information problems typically arise directly from the external world--inputs stimulate noumena and clouds. The information problem may also arise from a stable knowledge state when a cloud is deactivated or a new cloud is added to extend thought. As new clouds are activated, the knowledge state can stabilize quickly as many noumena from active clouds overlap (e.g. as one thought leads logically to the next) or the knowledge state can become less stable as noumena do not fit into active clouds. In the latter case, information is needed (e.g., finding out what one does not know may be a revelation that informs and guides subsequent action).

Note that each of these characterizations is based on information imparting some cognitive change, not on overt behaviors. There is a great range in the degree of cognitive change a person may seek. For example, physicians often seek information to confirm what they believe to be the proper course of treatment. The need to confirm information does not change cognitive structure so much as reinforce it. Regardless of the terminology used and the motivation, the information problem is the trigger for information seeking and as discussed in sections ahead, it evolves and changes as the search and the overall situation progress.

Task.

A *task*, as used here, is the manifestation of an information seeker's problem and is what drives information seeking actions. The task includes an articulation, typically stated as a question, and the mental and physical behaviors of interacting with search systems and reflecting on outcomes. Tasks are composed of entity-relationship states and plans for expanding those states to some goal state. Although tasks are explicitly goal driven, the human element and the interactive nature of information seeking allow the goal and therefore the task to change or evolve as search progresses. The balance between goal-driven initiation and data-driven progress and change are one measure of browsing considered in Chapter 6. As information seekers define the information problem, they identify concepts and relationships and assign terms[6] to the concepts in order to articulate a task. These concepts and terms vary in number (the number of noumenal clouds) and in degree of abstractness (the amount of variability possible when mapping noumena to specific objects or events), and these variations determine the task complexity[7].

In addition to complexity, tasks may be characterized according to their goals or the answers expected. A key problem in information-seeking performance and information system design is clarifying different levels of task goal. For example, the goal from a system point of view is to provide a document of some sort whereas the goal from the information seeker's point of view is to extract information (make meaning) from some document and stabilize or embellish their knowledge state. From the information seeker's point of view, answers to questions (goals for tasks) may be characterized along three continuua: specificity, quantity, and timeliness.

The specificity of a goal can range from single fact to an idea to an interpretation or opinion. In the case of facts, the information seeker is assured of a high level of certainty that they have accomplished the task and reached the goal. This is not to say that the answer is necessarily optimal, but there is typically a high degree of confidence in the validity of the result. In the case of ideas, the certainty of attainment and therefore of terminating search is less well-defined. Such tasks may invite subsequent iterations of action and termination decisions based on factors such as time or resource constraints. Additionally, these types of answers are often multiple in number and information seekers must choose or synthesize outcomes. Goals with very low specificity offer the greatest challenges to information seekers since they provide low levels of certainty about task completion and require great efforts to develop confidence in the validity of one of possibly many interpretations.

Related to specificity is the volume of the answer as measured either in information bits or time for users to process the result. At one end of this continuum we have a single word, date, or image that satisfies the task. Such goals are often satisfied by ready reference services in libraries, telephone directory assistance, or traditional database management systems. Such answers can be transmitted and processed easily and quickly. Another level of volume requires one or more documents and these answers take more time to transmit and process. Most importantly, these levels of goal volume traditionally require information seekers to process and extract information. This makes relevance judgments on the part of information seekers both more personal and difficult with subsequent implications for the evaluation of system performance. In the most extreme case, such as the task of "keeping abreast of one's field," the volume of the answer reaches large subsets of a domain or domains. These goals are typically met by regular reading of periodicals, discussions and exchanges with colleagues, and participation in courses, workshops, and conferences.

Timeliness of the goal describes the expected time to completion. One of the common frustrations of information seeking is when expectations of timeliness are far out of sync with actual times to completion. Thus, regardless of how effective an information service is, if the information seeker expects the task to take ten minutes and it actually takes two hours, there will be disappointment. At one end of the timeliness continuum are answers we expect to ascertain immediately or in a few minutes. We can only have such immediate expectations for high specificity, low quantity level goals. These types of answers are not insignificant, however, because they are common and they highlight one of the distinctions between information seeking and learning. They are common in that they include things we once knew but have temporarily forgotten or things we need as an intermediate step in some larger task; thus we ask someone proximate to us, or we execute a quick lookup in a reference book, dictionary, or service. In many cases, we have no intention of ever using the information again and thus acquire it for immediate needs without making mental or external notes. This is in strong contradistinction to learning which always aspires to retention of information acquired. Many tasks aim at goals that we expect will be achieved in some generally defined period such as minutes, days, or months. These tasks include most formal information retrieval such as database searching, interlibrary loan requests, and written requests to individuals or institutions. At the most extreme, our expectations are that we will never fully achieve our task but will inexorably progress toward it. Such tasks are accretional in nature, are part of expert learning, and distinguish information seeking from information retrieval.

All these characteristics of task goals work together to define the cost of the task. The total cost is not composed of simply external costs such as connect and copying charges, but personal costs such as time, and cognitive and emotional resources. Early estimates of the costs are computed by information seekers to determine whether tasks should be defined and executed. These estimates are strongly influenced by personal abilities and motivations, especially with respect to personal information infrastructures.

Search system.

The *search system* is a source that represents knowledge and provides tools and rules for accessing and using that knowledge. A search system is here taken most generally, and includes, for example, people, books, libraries, and maps, as well as a variety of electronic information systems. A search system represents knowledge in what will be called a database, regardless of whether the search system is a book, a computer, or a person. Thus, a *database* refers to the knowledge potentially available to an information seeker. The representations of that knowledge and the tools, rules, and mechanisms for accessing and manipulating it will be called an *interface*.

The search system supports information seeking by structuring knowledge and constraining access. The way knowledge is organized and made available affects the way information seekers are able to access this knowledge and thus their information-seeking performance. Information seekers construct and apply mental models for search systems to execute information-seeking tasks.

Both the database and interface have conceptual and physical components. Figure 3.2 illustrates these components. The interface serves as an intermediary between the user and the database. Conceptual elements include representations and mechanisms and physical elements include input/output devices. The database content may exist in different containers (e.g., a paper and electronic version of a text). The database and interface may be integrated or separated physically or conceptually. The interface should provide robust mappings between the database content and the conceptual representations information seekers manipulate. In the sections that follow, three general types of search systems--a book, an electronic retrieval system, and an expert human--are used to illustrate and clarify search system characteristics.

[Insert Figure 3.2. about here]

Database: Content and container. Information seekers are most concerned with the content of a database. Content may be characterized by its topicality, aim, data type, quantity, quality, and granularity. The primary aspect of content is "aboutness," the domain represented by the database. Clearly, an information problem related to nuclear waste management will not likely be well-served by a database about ancient Roman poetry. Books can be assigned subject headings that aim to capture their primary topics, electronic retrieval systems have data dictionaries that specify what entities and relationships are included, and people develop expertise in specific domains[8].

A second aspect of the content is whether it is primary or n-ary in nature. Secondary (e.g, bibliographic) or tertiary (e.g., bibliography of bibliographies, database guides, directories of electronic servers, etc.) databases are important for locating primary databases and information seekers must have clear images of the intermediate role they play. The classic disappointment in electronic environments is illustrated by students who use a CD-ROM index to conduct a search and then are dismayed that they must locate the periodical in the library. It is important that the information seeker understand which level of access is most appropriate to reach the primary database relevant to their problem.

Another aspect of the database content is the type of information it contains, e.g., text, numeric, graphic, verbal, kinesthetic, mixed, etc. These types of information constrain how system designers organize, index, and display information. This in turn influences the strategies that information seekers use to locate, scan and extract information. Books often include mixed forms, electronic multimedia databases are becoming more common, and humans offer a broad range of verbal and kinesthetic information.

The quantity and quality of database content are also important aspects. It makes a great difference to an information seeker in terms of effort and expectations whether the database consists of a single book of 200 pages or an entire shelf of books on the topic. Likewise, an electronic system of 1000 records can be treated quite differently by an information seeker than a system with a billion records. Although human memory is for all practical purposes infinite[9], different people are able to provide different degrees of experience and expertise on a topic. Experienced information seekers assess the accuracy of the content as part of search system selection and while making judgments about initiating and terminating search. The authority of a book's author, the integrity of an electronic retrieval system, and the credibility of human experts are each taken into consideration by experienced information seekers. In addition to accuracy, the database content must be clearly organized and presented if it is to be considered a quality information source. Books can be wellwritten or not, electronic documents can be well-structured or not, and human experts can be logical and articulate or not.

Finally, the granularity of the database content affects information seeking. Books, databases, and people can represent knowledge at very specific or highly general levels, with respectively increasing levels of variability according to the needs of the information seeker. For example, a book, electronic system, or person can represent information on dogs in general or be specific to the sleeping habits of a particular family of dogs. Experienced information seekers expect an encyclopedia to provide generic information on a variety of topics but emerging electronic environments have yet to establish specializations and precedents for communicating granularity to users. For example, an electronic archive may indiscriminately mix highly specific commentary on minor points of an electronic forum with generic overview information on the topic.

Databases have physical attributes that affect information seeking. These attributes may be though of as the "container" for the contents, and include the hardware, media, and physical organization of the system. For a book, the attributes are related to size and weight, printing (e.g., characteristics of paper, glue and ink), typography, and the author's physical ordering of ideas. From a computing point of view, these attributes are related to computational power, storage capacity, coding mechanisms, display characteristics, and data structures. For example, computational power determines whether graphical interfaces can be used effectively, or whether sophisticated retrieval schemes will operate in a timely manner; and CD-ROM media constrain data organization since data is coded along a spiralled surface rather than on directly accessible track/sectors or arrays. From a human point of view, physical attributes are related to mental and verbal capabilities, and training or biases.

A significant influence of the container is how it constrains organizational presentation. Books generally invite sequential presentations and traversals, although there are many ways linearity can be disrupted (e.g., footnotes, citations, indexes, figures, etc.). Electronic systems have the potential to use networks, webs, and arrays to invite associational traversals--the basis for hypertext. Additionally, the processing and structuring of data determines whether retrieval features such as ranking and relevance feedback are available. For example, an inverted index and a primary file together facilitate rapid exact match retrieval; a file of vector values and a primary file facilitate ranked retrieval; and both leverage the preprocessing captured in the access files to outperform a simple primary file searched in sequential fashion. Humans can present in free-associational or in carefully sequenced fashion and information seekers can "traverse" these presentations in random snatches or in sequence. Whether linear organization and presentation of ideas is inherently more transferrable by people, or our culture has been conditioned by the limits of transmissional technology is a research topic that will continue to occupy generations to come.

Interface: Physical and conceptual. The interface is a communication channel between a user and a machine. Interfaces have physical and conceptual components and the concept of interface is evolving as people use computers as intermediaries for collaborative work (e.g, Grudin, 1993). Physical input/output devices, selection and feedback mechanisms, and retrieval rules characterize an interface and serve as portals to the content. The interface determines how learnable, usable, and satisfying a search system is, and therefore, affects information-seeking performance. The "look and feel" of a book, electronic document, or person is dependent on assumptions made about the information seeker's needs and abilities. For books, these assumptions are stable, and for humans the assumptions are dynamic and may be personalized to each individual information seeker. For most electronic systems, these assumptions (the user model, Allen, 1990; Daniels, 1986) are in practice fairly stable and depend on a set of default conditions that reflect the system designer's view of typical information seekers and their information problems. Some systems have adaptable user models that are controllable by the user (e.g., allow information seekers to use command or menu modes), and research proposals for automatically adaptive interfaces continue to find support (e.g., Hefley, 1990). Interfaces for electronic search systems have received substantial attention, and developments in end-user interfaces have contributed to the adoption of information retrieval technology by a variety of groups and organizations.

The physical interface is composed of objects that facilitate input and output, and that control interaction. For books, input to the system is limited to using separate tools such as pencils or highlighters to mark text or write notes. For electronic retrieval systems, input is typically done through keyboards, although mice and touchpanels are common, and speech recognizers, eye trackers, data gloves, and other devices are finding increasing application (Jacob, Legget, Myers, & Pausch, 1993). Input to another person is via the entire range of the human communication spectrum, including voice, body language and gesture, and intermediated channels such as paper and chalkboards.

Output is constrained by the database's container. Output from books takes the form of clear, systematic arrangements of inks on paper illuminated by a light source. Many qualitatively distinct techniques have been developed in the hundreds of years books have been produced. Output from an electronic system is typically through a visual display unit[10], although printers are common, and speech synthesizers are finding wider use. Output from a human expert may come via any of the channels listed for human input above.

Objects that control interaction are dependent on the physical containers discussed under databases above. There are physical constraints on exchange between the information seeker and the search system. Books are static in that the author makes all decisions about what it is possible to see and the information seeker makes all decisions about how to see it, with no exchange between the two. In electronic systems, it is possible that authors can provide many alternative views of the material and information seekers can add, modify, or delete information. Moreover, the electronic system can offer usage-sensitive help or error diagnosis that is dependent on the information seeker's actions. Human information systems are most interactive, allowing control through interpersonal dynamics. Physical interfaces for electronic systems have made dramatic progress and have significantly improved the interactivity of information seeking. This trend will likely continue as alternative devices and the coordination of multiple devices evolve[11].

The conceptual interface of a search system delimits the rules and protocols for information transfer. The main categories of the conceptual interface are: interaction style, representational structure, and search mechanisms. Interaction style encompasses the mode of communication, including selection and feedback mechanisms. In the case of books, this communication is simplex[12], that is, the book acts exclusively as a source and the information seeker as destination. For electronic systems, there are four types of interaction style: commands, form fill-in, menus, and direct manipulation (Shneiderman, 1992).

Command driven interfaces depend on the information seeker knowing a specific language in order to manipulate the system. Most information retrieval systems are either strictly command driven or provide a command interface as an option. Command-driven interfaces are generally preferred by experts since they are efficient to use (once they are learned), and often are extensible to facilitate short-cuts or highly specialized tasks. Command languages are so pervasive that there are international standards committees working to develop a common command language for computer to computer communication, thus allowing information seekers to use familiar command languages available on their local machines (NISO, 1989).

Form fill-in interaction styles prompt the user with blank forms to complete. Although all the slots to fill in are defined in advance, users have wide discretion in what they put in the slots. Form fill-ins are thus a cross between command and menu styles. Menu-driven systems have become increasingly popular and allow novice or casual users to execute information-seeking tasks without knowing a command language. Menu systems fully limit the actions an information seeker may take and thus do not allow the expressiveness of command styles. Menu-driven systems are half-duplex, in that users make selections and the system provides feedback and then another menu.

Direct manipulation styles provide the information seeker with explicit mappings between their physical activities and system responses. Direct manipulation demands rapid, reversible selections and feedback (Shneiderman, 1983). Sliding a mouse along a pad and watching the cursor slide along the screen in the same direction and at a proportional rate is an example of direct manipulation. Direct manipulation interaction styles make the system "transparent" in that users are able to focus on the task at hand rather than manipulating the system as an intermediary between themselves and the database contents. Direct manipulation is one of the key components to highly interactive, advanced information-seeking systems. Direct manipulation systems are more closely full-duplex than other interaction styles since selections and feedback are nearly simultaneous. Another person as a search system is the ultimate in a directly manipulable interface. Although verbal language is mostly half-duplex, the multiple modes of interaction that occur as humans communicate provide rapid and reversible stimulus-feedback. Direct manipulation is most obviously applicable to tasks with physical analogs, but examples of direct manipulation interfaces for abstract tasks such as information seeking have begun to emerge (Shneiderman, 1992, especially Chapter 11).

Another characteristic of interaction style is the metaphor of action supported by the search system. Books emulate verbal activity, often lecture or argument in the case of nonfiction. The metaphor of narration or thought (stream of consciousness) is often used in fiction. Electronic search systems often use the book as a metaphor--displaying screens of text or tables of data. The desktop has become a popular metaphor for today's variety of applications and new metaphors such as agents and theater stages (Laurel, 1991) have been proposed. People do not need metaphors for other people, since other minds are ultimately the source of all information and the assumption that facilitates communication is that other people's minds work in basically the same fashion as one's own.

The representational structure of an interface refers to the organizations of information and the physical mechanisms required to manipulate the structure. It is here that domain experts offer valuable contributions to interface design since they have good understandings for how the content should be partitioned and aggregated to answer the broadest range of questions. In the case of books, themes may be presented hierarchically, or may be interwoven in webs or spirals throughout what may be a primarily linear set of physical pages. Alternative or supplemental representations such as tables or figures may be used to augment key concepts. Links among physically disparate words, phrases, and concepts occur in footnotes, tables of contents and indexes, and as anaphora within sentences or documents, and as allusions and metaphors beyond documents. The physical mechanisms to manage these links is primarily dependent on alphabetical ordering principles, parentheticals, page numbers, and citations. Conceptual links are dependent on the reader's knowledge and experience in the domain.

Electronic search systems support linear, hierarchical, or network structures for content as does paper, and have the potential of providing alternative representations according to user needs. This potential for providing many levels of representation or alternative representations is an essential distinction between manual, static environments and electronic, dynamic environments. This point is illustrated and discussed in detail in Chapter 7. The cost of flexible representations is in the various mechanisms for controlling them. Today's systems are strictly limited to three management mechanisms: paging, scrolling, and jumping. Systems often provide scroll bars, sliders, pop-up menus, and displays in windows that may be resized or overlapped--requiring users to develop new strategies for manipulating the physical structure of information. One result of such representational structuring is the common complaint by novices that it is difficult to know how large is a specific document. Another is the additional attention that must be given to managing multiple windows on the screen.

One approach to simplifying representation problems is to separate the representations the information seeker manipulates in the interface from the representations the interface manipulates in the database. In database management systems, logical and conceptual schemes serve this function. In these systems, the logical scheme for a database is distinct from the physical scheme that defines data storage. The logical scheme makes it possible for different users to have distinct views of the database according to their specific requirements and access privileges. The logical scheme also determines how queries must be specified (e.g, in SQL language), that is, there are explicit mappings between the conceptual interfaces provided by the query language and the physical scheme of the stored data. This distinction between logical and physical data organization makes database management systems usable by end users. Another example is provided by what is known as the client-server model, where a local interface (client) can be used by the end user to access a remote system with its own logical and physical interface by virtue of an automatic network intermediary that transparently facilitates exchange (Lynch, 1991).

People are capable of all types of organizational structures, although, teachers and information specialists invest effort to present information in consistent and direct fashion according to the perceived needs of the learner or information seeker[13]. Moreover, human intelligence allows instant repairs to be made as communication breakdowns occur.

All search systems provide specific features that define and constrain search. Books provide tables of contents, section headings, citations, and indexes to support direct search for specific information, and primarily encourage scanning and linear reading. Electronic search systems can support these same types of search features, but also can allow string search, Boolean logic queries, ranking of results, and relevance feedback. A grand challenge for interface designers is to create new features that take advantage of the unique characteristics of the electronic medium. People are only constrained by their knowledge and ability to articulate their ideas. Paper, electronic, and human search systems will continue to be used and well-developed personal information infrastructures will allow information seekers to ascertain which features are most appropriate to the task and select the system that best supports those features.

Domain.
A *domain* is a body of knowledge (e.g., history or chemistry) composed of entities and relationships[14]. Domains vary in complexity, number of entities and relationships, specificity, similarity of the entities and relationships, evolutionary status, clarity of definition of the entities and relationships, and their rate of growth and change. These characteristics determine the type and amount of information, and level of organization for a domain. Most domains are dependent on textual representations of information, but some are dominated by graphical (e.g., art, architecture), audio (e.g., music), kinesthetic (e.g, dance, sports), or multiple information forms (e.g, film, journalism). The amount of information and level of organization vary immensely across domains. Some fields have enormous and diverse bodies of rapidly growing literature that spawn dozens of subdomains (e.g, medicine) whereas others are fairly contained and growing slowly (e.g., classics). Some fields have inherent ordering relationships that provide important access points for information seeking. For example, history leverages chronology and geopolitical units, anatomy take advantage of subsystems of the body, and the arts depend on individual artists.

The domain is important because it affects several of the subprocesses that make up the information-seeking process. For example, domains employ different mixes of search systems and search strategies. A domain like hematology offers substantial online information from various vendors in various forms, from abstracts to full texts. On the other hand, a domain like contemporary music offers little online information and limited access through such common entry points as subject headings. Differences between information in the sciences and humanities are well-known. For example, information in the humanities typically does not go out of date whereas scientific and technical information ages rapidly; humanities publications are less likely to have multiple authors; the humanities make equal use of books and journals, whereas, the sciences favor journals; and abstracting standards apply more readily to technical literature than to historical literature (Corkill & Mann, 1978; Tibbo, 1989). These characteristics affect the way search systems are organized and how information seekers access them.

Scholars in all fields use a wide array of information sources, especially colleagues, however, distinct domains have sources that are frequently used. For example, business practitioners primarily use trade journals, trade associations, and word-of-mouth rather than libraries and books (Arthur Little Inc., 1967); physicians primarily use desk reference sets, textbooks, journals, and other professionals, especially colleagues (Connelly et al, 1990; Covell et al;, 1985). Studies of these and other professionals (e.g., clinical psychologists, Prescott & Griffith, 1970; professors, Kwasnik, 1989) agree that information seekers prefer interactive sources of information to static sources. Conversations with others who may have the information they need, conferences, workshops, and symposia are always listed as highly important sources of information in these studies, and some have expressed desires to have more active forms of information available such as audio and videotapes or computer programs and simulations.

Setting.

The setting within which information seeking takes place constrains the search process. *Setting* here is taken to have physical and conceptual/social components, including whether the task is done in collaboration or alone and the information seeker's physical and psychological states. As such, it corresponds to the context or situation as described by Suchman (1987). This perspective of situated action has been applied in education by Brown, Collins, & Duguid (1989), Garner (1990) and Bransford, Sherwood, Hasselbring, Kinzer, & Williams (1990) and in human computer interaction by Carroll (1990), and Suchman (1987).

The physical setting determines physical constraints such as amount of time allocated, physical accessibility, comfort, degree of distraction, and cost. It makes a considerable difference whether one is seeking information in a private office or in a public place with a line of impatient people nearby. Physical features such as lighting requirements for paper, and electricity and hardware for electronic information are often assumed in modern environments, but are basic setting characteristics nonetheless. Economic constraints such as cost and time are situational and influence whether and how tasks are initiated, executed, and terminated. Proximity of sources is a well-documented factor in information seeking, with personal collections and proximate co-workers the most commonly used information sources (e.g., Allen, 1977). Electronic networks have begun to have significant influence on information proximity by providing access to catalogs and primary materials from one's home or office workstation. Additionally, electronic networks offer new opportunities for group collaboration on information-intensive tasks (see Grudin, 1991 for an overview). The physical setting also includes the type of access and procedures for obtaining access. Whether the information is accessed in a personal or shared work area, and in paper form or electronic form affects overall information seeking. Additionally, what forms must be completed, permissions secured, or identification cards shown, influence overall willingness to seek information and its costliness.

Conceptually, the setting includes the psychological and social ecology of information seeking. The cognitive aspects of this ecology were described in Dervin's (1977) situation phase of her sense-making model. These aspects may be considered to be the state of a person's working memory at any given time. Other psychological factors include a person's self-confidence in an environment. Self-confidence typically depends on familiarity with a situation or expertise in the problem area, and influences how readily the information seeker is to take intellectual risks and to persevere in spite of intermittent failures. The social ecology of a situation relates the individual to other individuals or groups and to organizations. One's role in an organization determines self-image and influences self-confidence, alertness, and ultimately, productivity. For example, people with low status in an organization may be less able or willing to use organizational resources to seek information. The organizational structure and procedures as described in the physical setting above also influence how participants interact with the overall organization and other people, including for purposes of information seeking. Social considerations for information seeking will become increasingly important as groups use technologies to collaborate on information-intensive projects.

Outcomes.

Outcomes for information seeking include both products and a process. As products, outcomes are the results of using an information system, that is, feedback from the system. Eventually, if all goes well, an outcome or set of outcomes will serve as attainment of the task goal operationalized as an answer to the question, and upon reflection, as solution to the information problem. These products range from individual words, phrases or images provided by a source, to intermediate sets of document surrogates, to complete documents that are organized and displayed to aid the information seeker in interpretation and use. Most outcomes are intermediate stages in the information-seeking process that provide information to further the overall process. Thus, outcomes affect the task and subsequent iterations of information seeking. Outcomes affect the user as well, since they change the state of the information seeker's knowledge, that is, they impart information.

Outcomes also serve as objects of evaluation to assess search or system effectiveness. Typical measures of search products include assessments of relevance or utility during or after search--including such quantitative measures as recall and precision, structured or informal subjective evaluations, and examination of the resultant products or artifacts (e.g., documents or abstracts). The behavioral moves made by information seekers also help in evaluating performance since evaluators assume that searcher behaviors are manifestations of internal information-seeking strategies, which are themselves "runs" of the searcher's mental models for the search system.

Outcomes can also be viewed as mental reflection on information seeking episodes. As such, a trace of the search process is itself an outcome since information seekers consider the mental and physical actions taken during information seeking and adapt their personal information infrastructures accordingly. Thus, the experience itself becomes part of the searcher's knowledge for dealing with future information problems. Because of the powerful roles outcomes play in information seeking, consistent and effective management and manipulation of outcomes is critical to information system design.

Summary of factors.
The information seeking factors are not mutually exclusive and are linked by relationships that vary in complexity and importance. The relationships can be considered in pairwise fashion for simplicity, but ultimately, the full interactions among the factors determine information-seeking activity. The framework is human-centered and the information seeker is responsible for integrating all the factors.

- The information seeker's problem considered in light of the personal information infrastructure manifests the task; the information seeker's mental model for the search system strongly influences performance and the system influences this by presenting a user model that represents the designer's view of generic information seekers; the information seeker may have highly developed or novice understandings of the domain; the information seeker is influenced by the setting and may exert some control over it; and outcomes are determined by the information seeker's actions and likewise themselves determine subsequent actions.
- The task influences which system is selected and the system constrains how the task can be operationalized; the task rarely influences the domain, but the domain can influence the nature and result of the task; the task and setting are weakly related both ways; and the task determines outcomes since outcomes are incremental goals for the task and in turn may lead to modifications of the task.
- The search system is dependent on the domain for its content, but examples of how the search system may have an impact on the domain have just begun to emerge[15]; the system is a part of the setting and in extreme cases (e.g., power outages) the physical setting can influence the system; and the system is a determinant of outcomes, and given the present state of system development,

only in the case of human search systems does the system learn or change based on outcomes.

- The domain and setting have little influence on one another, and the domain has some weak influence on particular outcomes.
- Finally, the setting weakly influences outcomes, but outcomes only rarely and then indirectly influence the setting. These relationships are admittedly subjective, but are useful to gain an overall sense of how the information-seeking factors interact. Of course, information seeking is determined by the concurrent interactions among all these factors. The main idea is that the framework is user-centered and action-oriented, as described in the process presented in the following section.

INFORMATION-SEEKING PROCESS

The information-seeking process is both systematic and opportunistic. The degree to which a search exhibits algorithms, heuristics, and serendipity is dependent on the strategic decisions the information seeker makes and how the information-seeking factors interact as search progresses. The information-seeking process is composed of a set of subprocesses as depicted in Figure 3.3. Information seeking begins with the recognition and acceptance of the problem and continues until the problem is resolved or abandoned. In the figure, the likelihood of a subprocess calling another subprocess is represented crudely by three types of arcs. Bold, solid arcs represent the most likely (default) transitions from one subprocess to another, dashed arcs represent high-probability transitions, and solid arcs represent low-transition probabilities. These subprocesses may default to phases or steps in a sequential algorithm, but they are better considered as functions or activity modules that may be called into action recursively at any time, that may be continuously active (types of sentinels or demons), that are temporarily frozen while others proceed, and that may make calls to other subprocess. Thus, the information seeking process can proceed along parallel lines of progress and take advantage of opportunities arising from intermediate or random results. The degree to which the information-seeking process deviates from a top-down, sequential default provides a basis for characterizing browsing and analytical search, and the number of iterations (cycles) per unit time serves as a gross measure of interactivity.

[Figure 3.3. about here]

Recognize and accept an information problem.

Recognizing and accepting an information problem can be internally motivated (e.g., curiosity about details of immediate thought) or externally motivated (e.g., teacher asking a question or making an assignment). The problem may be characterized as a gap (Dervin, 1977), a visceral need (Taylor, 1962), an anomaly (Belkin, 1980), as a defect in a mental model, or as an unstable collection of noumenal clouds, but it is manifested as a resource demand on the perceptual or memory systems--the person becomes “aware” of the problem. At this point, the problem may be suppressed or accepted. Suppression is influenced by setting and the information seeker's judgment about the immediate costs (physical and mental) to initiate search (e.g., "This is not worth the effort; I'll worry about this later"). In the case where the information seeker judges the situation appropriate, he/she accepts the problem and begins to define it for the purposes of search. Acceptance is influenced by knowledge about the task domain, by the setting, by knowledge of search systems, and by the information seeker's confidence in his/her personal information infrastructure. Recognition and acceptance are typically ignored by system designers since they are viewed as user-specific and uncontrollable. However, systems that invite interaction and support satisfying engagement will lead users to accept information problems more readily. Attention to this subprocess also reinforces user control and volition in any intellectual activity. Problem acceptance initiates problem definition.

Define and understand the problem.

Problem definition is a critical step in the information-seeking process[16]. This subprocess remains active as long as information seeking progresses. Note that in Figure 3.3 most subprocesses have high probability transitions back to problem definition. Understanding is dependent on knowledge of the task domain and may also be influenced by the setting. The cognitive processes that identify key concepts and relationships lead to a definition of the problem that is articulated as an information-seeking task. For intermediated information seeking, the intermediary conducts a reference interview to accomplish this subprocess (Auster & Lawton, 1984; White, 1985). In end-user searching this step is often assumed or abbreviated--a major cause of end user frustration and failure.

To understand and define the problem, it must be limited, labeled, and a form or frame for the answer determined. The problem may be limited by identifying related knowledge or similar problems or by listing what specific knowledge is not related. Concepts, words, phrases, events, or people related to the problem can be listed and grouped into categories that serve as the basis for assigning labels and problem statements. This process represents what Taylor called the conscious need. The information seeker may hypothesize what the answer will be, but at least creates an expectation of what the answer will "look like", e.g., will be a date, a fact, a route, an idea, an interpretation, an expression, etc. There may also emerge an expectation of the physical form of the answer (e.g., texts with tables, an image with an annotation, ideas shaped from interactions with various people and documents, etc) which, in turn, strongly influences the selection of a search system. These expectations about outcomes ultimately guide (and bias) action. The limiting, labeling, and framing of solution properties lead to the articulation of an information-seeking task, what Taylor referred to as the formalized need. During problem definition the information seeker represents the problem internally as a task with properties that allow progress to be judged and determines a general strategy to use for subsequent steps.

Choose a search system.

Choosing a search system is dependent on the information seeker's previous experience with the task domain, the scope of his/her personal information infrastructure, and the expectations about the answer that may have been formed during problem definition and task development. Domain knowledge is a powerful variable in selecting a search system and focusing search. Experts in a domain have experience with the primary search systems specific to the domain. Economists in our studies were able to make spontaneous judgments about whether information required for assigned information problems was likely to be found in one journal or another. Likewise, attorneys were readily able to determine whether information in their assigned searches would be found in case law, statutes, or treatises. In both these cases, some professional intermediaries who regularly conducted searches in these domains were also able to predict where relevant information would be found (Marchionini, Dwiggins, Katz, & Lin, 1993).

The information seeker's personal information infrastructure is dependent on past experience with information problems in general, their general cognitive abilities, and experience with particular systems. It is well-known that information seekers prefer colleagues or human sources before formal sources, and then proximate sources of information and easy to use systems. These preferences are powerful factors in information seeking and reflect natural human efforts to minimize costs, especially to seek the path of least cognitive resistance (Marchionini, 1987). Naive information seekers have default search systems they turn to for many tasks. For example, Marchionini (1989b) found that high school students used books and encyclopedias as default sources for a variety of information problems. When experienced information seekers are faced with tasks in foreign domains, they often seek general background information in reference systems that will help refine the problem and point them to primary search systems.

Given the constraints of domain knowledge, general cognitive conditions, and previous search experience, information seekers endeavor to map the search task onto one or more search systems. The mapping process takes into consideration the type of task, (e.g., complexity, specificity of answer, etc.) and characteristics of available or familiar search systems. In actual practice, information seekers consult several search systems as they move toward solutions to their problems. For example, in libraries, information seekers may ask a reference librarian where to begin searching, they may consult an index or a card catalog, and eventually one or more journal or book primary sources. As electronic search systems and network access proliferate, there are a plethora of potential sources available to information seekers. It is becoming increasingly important to use secondary or n-ary systems to limit the time and effort spent locating and using primary systems. With a few exceptions[17] today's electronic systems are specific to one or two particular levels of search (e.g., bibliographic records) rather than providing a common interface to many levels of systems. For example, there are expert systems that emulate a reference service, thousands of online bibliographic databases, and hundreds of online or CD-ROM full-text databases. Filtering, ordering, and selecting the collection of sources will become increasingly important to mapping tasks onto search systems.

Formulate a query.

Query formulation involves matching understanding of the task with the system selected. In many cases, the first query formulation identifies an entry point to the search system and is followed by browsing and/or query reformulations. Query formulation involves two kinds of mappings: a semantic mapping of the information seeker's vocabulary used to articulate the task onto the system's vocabulary used to gain access to the content; and an action mapping of the strategies and tactics the information seeker deems best to forward the task onto the rules and features the system interface allows.

Semantic mapping is similar to moving from Taylor's formalized need to the compromised need (1962) and is highly influenced by earlier mappings from the sensation (visceral need) that causes attention to a problem (conscious need) and the mappings during problem definition from fuzzy noumena and general concepts to specific terms and concept classes (formalized need). In general, this mapping takes as domain the entire set of identifiers (possible expressions) available to an individual information seeker, and the complete set of identifiers (recognizable expressions) available to a system as range. The mapping function most commonly takes words (rather than phrases or concepts) associated with the task onto the set of words that serve as entry points (indexed words or controlled vocabulary) to the system content. For static search systems such as books, the information seeker has total control (and responsibility) for the mapping and aims to match words/phrases from the task statement itself (or terms related to them), with words/phrases in the title, index, table of contents, headings, list of keywords, and text. For dynamic search systems such as people, the intelligence of both parties can be applied to enrich the mapping function since the controlled vocabulary of a human is both large (in fact is the same as the entire content vocabulary) and more associationally connected. Thus, experts in a domain not only know more terms that directly relate to the information seeker's query formulation, but they can also add additional terms and interact with the information seeker to clarify and verify the query. In the case of professional intermediaries, the process of developing a query formulation is part of the reference interview and has been shown to be an important determinant of intermediary performance.

In the case of electronic search systems, the query formulation process is partially dynamic and there are a wide range of techniques system designers have used to assist the information seeker. Such techniques include: expert system intermediaries (Croft & Thompson 1987; Marcus, 1983); online suggestions (Meadow, 1988); query-by-example (Zloof, 1977); dynamic queries (Shneiderman, 1992); and hypertext (Croft & Turtle, 1989; Frisse, 1988; Marchionini & Shneiderman, 1988). An electronic system may have a strictly controlled vocabulary (e.g., field names in a database) or a full-text vocabulary (e.g., inverted file), each clearly affecting the cardinality of the resultant set of items retrieved as a result of applying a mapping. The problem of representing concepts in document sets is a fundamental problem in information science and is considered from several perspectives in subsequent chapters.

Action mappings take possible sets of actions to the inputs a search system can recognize. If semantic mappings are thought of as "what" or declarative in nature, then, action mappings are "how" or procedural in nature. Just as a search system constrains the vocabulary an information seeker may use in query formulation, search systems also constrain how queries may be expressed. For example, humans recognize spoken or written expressions but books do not, and electronic systems have not yet accomplished any but rudimentary or highly constrained recognitions. Electronic systems may support Boolean expressions and provide special syntax for how these expressions may be made. Electronic systems may allow users to enter any terms they wish, or provide a menu that completely specifies all possible terms, or provide traversable links among various partitions of the database. At even more detailed levels, the system demands that users specify terms or previous sets using explicit characters, type cases, or punctuation.

Marchionini (1992) has argued that electronic systems have made many of their greatest contributions to information seeking at the query formulation phase. These advances have been significant in the area of action mappings thus far, in that electronic systems provide a much broader range of ways to articulate queries, albeit these ways are spread across different systems rather than generally available in a single system at the discretion of the information seeker. Progress in augmenting information seekers' mapping of task vocabulary to system vocabulary has been more difficult, but human-computer dialogues and machine inferencing have yielded promising directions for aiding semantic mappings.

Execute search.

Execution of the physical actions to query an information source is driven by the information seeker's mental model of the search system. Execution is based on the semantic and action mappings developed during query formulation. Conducting lookup requires actions like articulating a question verbally, picking up a volume, or pressing a key. For a card catalog, execution may entail selecting proper drawers and using alphabetical ordering rules; for an online database, execution may entail typing the query and sending it with a special keypress (e.g. return); for a hypertext, execution may entail browsing the database by following available links provided by the author.

Communication and computing technology has greatly affected how searches are executed (and consequently, if or when they are executed) by altering the physical actions necessary. Phone calls, telefacimilies and electronic mail make execution of a search with a human search system much more feasible, and electronic networks allow direct queries of remote collections from a home or office. Although interfaces for these devices are often complicated and frustrating, the effects of executing information-seeking tasks in physically proximate space cannot be overestimated. Search execution is one of the most obvious changes wrought by electronic environments since information seekers perform much more constrained physical actions at workstations than they do in libraries or offices.

Examine results.
Executing a query results in a response from the search system. This response is an intermediate outcome and must be examined by the information seeker to assess progress toward meeting the goal of the information-seeking task. This examination is dependent on the quantity, type, and format of the response and involves judgments about the relevance of information contained in the response. Responses are provided by information systems in units specific to the type of database, for example, numeric values, bibliographic records, fixed-length fields, entire documents, specific images, or verbal expositions on a topic. A response to a query may contain zero, one, a few, or many of these units, often referred to as "hits".

The information problem and the user's personal information infrastructure cause the information seeker to have expectations about the number of units required to complete a task, although these expectations often change as information seeking progresses. For example, information seekers typically expect zero or one hit when searching a card catalog for a specific title, and zero, one, or many for a query about a topic (subject search). Users of print encyclopedias typically expect to find zero, one, or a few articles on a topic, and may be quite surprised to find hundreds of hits when using a full-text electronic encyclopedia for the same topic. A significant difference in printed and full-text electronic encyclopedias is that electronic systems often retrieve many articles, thus requiring another major decision point in the examination of results (Marchionini, 1989b).

When multiple hits are returned, they are usually presented as a set made up of document surrogates such as titles, bibliographic records, or descriptive identifiers. The way these sets are organized and presented affects how information seekers examine individual units, make relevance judgments, and decide what steps to take next. In a library, a set of catalog cards on a broad topic are ordered alphabetically according to the main entry for that document[18]. In a set of bibliographic records retrieved from an online search system, the items are often ordered in chronological order beginning with the most recent. In more advanced electronic retrieval systems, items may be ranked according to query term frequencies. In hypertext systems, explicit links to other units and implicit links such as next page, previous unit, or index lookups are provided by the database designer. The ordering of resultant sets becomes more important as the size of the set increases, and the ability to manipulate orderings of sets of items is recommended for all electronic search systems. The propensity of electronic systems to report large sets of documents significantly affects the examination of results subprocess, complicating the decision-making associated with selecting relevant items of information.

The information seeker must judge the relevance of individual retrieved units with respect to the information-seeking task at hand. Relevance is a central theme of information science and has been considered from both theoretical and practical perspectives. Cooper (1971) provided a definition of logical relevance as a formal basis for evaluation of retrieval systems, and Wilson (1973) described situational relevance as dependent on the particular information problem at hand. Situational relevance is more specific to the relevance judgments that information seekers make as they examine intermediate results of search (see Saracevic, 1976 for a review of the literature related to relevance in information science). From a practical perspective, relevance serves as the main criterion measure for computing performance measures such as recall and precision.

From an information seeker's perspective, relevance may be considered as a decision on what action to take next in the information-seeking process. Alternatives include: terminate search due to goal achievement; pursue the document more fully, i.e. examine again or more exhaustively; pursue the document later, i.e., note existence and location and continue examining other results; pursue implications of the document to the continuation of search (e.g., identify terms to use in subsequent queries), and either continue examining other results in this iteration, formulate a new query, or redefine the problem; reject the document completely and continue examining results; or reject the document and stop information seeking without accomplishing the task. Note that the examine results subprocess in Figure 3.3 is a major decision point with many arcs to other subprocesses.

The examination of specific items for relevance is obviously affected by the type (primary, secondary, numeric, graphic, textual, etc.) and the quantity (number of units or documents) of information in the retrieved set. For small sets of results, items can be scanned quickly, browsed systematically, or inspected comprehensively. For large sets of results, the set may be reduced by reformulating the query or semantically-related surrogates (e.g., titles, abstracts, thumbnail images, etc.) can be scanned to identify those that suggest more comprehensive relevance assessment. Marchionini and his colleagues have argued that information seekers are willing to scan substantial sets of textual or graphic documents if they are given appropriate display and control mechanisms (Marchionini, 1989b; Liebscher & Marchionini, 1988).

As with query formulation, electronic systems have made substantial progress in supporting examination of results. Ranked output and alternative orderings of output offer substantial advantages to experienced information seekers because they assist in managing large result sets. Display techniques such as highlighting query words in retrieved documents, presenting different levels of organizational details (e.g., table of contents and full text--Egan et al, 1989), fisheye views that cluster potentially relevant items in a spatially ordered manner (Furnas, 1986), and high-resolution graphic views of information in hierarchical displays (e.g., Card, Robertson, & Mackinlay, 1991).

Extract Information.
There is an inextricable relationship between judging information relevant and extracting the relevant information for all or part of the problem solution. Assessments about relevance cause information extraction actions to be taken, although, information can be relevant to the problem, but not fully meet the conditions of the task goal. If a retrieved document is judged relevant, the information seeker may choose to continue assessing its relevance by extracting and saving information or to defer extraction and continue examining results. In the latter case, the document will eventually be re-examined and a revised relevance assessment made based on what other documents were added to the relevant list and what experiential events the information seeker experienced since the previous relevance judgment.

To extract information, an information seeker applies skills such as reading, scanning, listening, classifying, copying, and storing information. In the case of secondary databases, extraction may entail copying or printing bibliographic citations to facilitate retrieval of actual documents. In the case of verbal questions to human experts, listening skills, clarification requests or restatements of the information in one's own words aid in extracting the information relevant to the task. In full-text systems, basic reading skills, scanning skills, use of structural features such as headings and outlines, and jumping from section to section aid in extracting relevant information[19].

As information is extracted, it is manipulated and integrated into the information seeker's knowledge of the domain. As more information is extracted and stored, new items may not be as relevant as they would have been previous to other items being manipulated and integrated. Information extraction often includes some physical action such as copying to paper or other medium and saving those copies in larger structures according to well-defined organizational rules. For electronic systems, some of the techniques for ordering and display mentioned in the previous section on examination will assist users by allowing them to cut and paste items easily, including the contextual components that may appear in other windows on the screen. Thus, saving a section outline from a table of contents, the paragraphs around the most relevant information, and a path or query statement that retrieved the document can all be extracted and aggregated easily. Electronic tools for cutting and pasting already offer substantial advantages for information extraction of text, static and moving images, and sound.

Reflect/iterate/stop.
An information search is seldom completed with only a single query and retrieved set. More often, the initial retrieved set serves as feedback for further query formulations and executions. Deciding when and how to iterate requires an assessment of the information-seeking process itself, how it relates to the acceptance of the problem and the expected effort, and how well the extracted information maps onto the task. Monitoring the progress of information seeking is particularly crucial to browsing strategies that are highly interactive and opportunistic. Determination of a stopping function may depend on external functions like setting or search system, or on internal functions like motivation, task domain knowledge, and information-seeking ability. Stopping decisions in full-text electronic systems are more complex because retrieval is both physically easier and yields more robust outcomes.

Summary of subprocesses.
The information-seeking process is dynamic and action-oriented. The concurrent activation of some subprocesses is not captured in Figure 3.3. Figure 3.4. illustrates some of this parallelism as well as depicting three classes of subprocesses: understanding, planning and execution, and evaluation and use. Note that problem definition and examination of results act as bridges across these three classes of action. The understanding subprocesses are mainly mental activities, planning and executing subprocesses are both mental and behavioral, as are the evaluation subprocesses.

[Figure 3.4. about here]

Because the subprocesses outlined above are controlled by the information seeker, they most often take heuristic or opportunistic paths according to skills and experience. These paths depend on ongoing judgments about the costs-benefits of progress being made, redefinements of the task goals, and relevance judgments about retrieved information. Electronic search systems have had substantial impact on several of the subprocesses, especially the query formulation and examination of result subprocesses. Highly interactive search systems and full-text databases have begun to blur boundaries across the subprocesses and tend to decrease the linearity of their progression.

The information-seeking framework is composed of factors that affect information seeking behavior and this dynamic, information seeker-centered process. In the chapters ahead we will examine more specifically how electronic environments affect information seeking and the information seeker. In the next chapter we revisit the information seeker and consider the building blocks for personal information infrastructures.

Chapter 3 Notes

1. Fidel & Soergel (1983) identified scores of interacting variables in eight categories that are related to online bibliographic retrieval. Their analysis included intermediaries as a major category as well as end users.

2. Precision is the ratio of relevant documents retrieved to the total number of documents retrieved; recall is the ratio of relevant documents retrieved to the total number of relevant documents in the database.

3. Note that this assignment of terms is dependent on the information seeker's vocabulary, not the system's. The mapping from personal to system terminology takes place later during query formulation.

4. Saracevic & Kantor (1988b) have classified questions into five categories: domain; clarity (semantic and syntactic); specificity (of both the task statement and the content of task); complexity (number of concepts); and presupposition (number of implied concepts not explicitly stated in the task statement). Marchionini and his colleagues (Wang, Liebscher, & Marchionini, 1988) used five criteria to classify questions in their studies of hypertext use: complexity (number of concepts); specificity (variability of appropriate answers); focus (determinability of the primary concept); path (the length of the optimal route to find the answer in a specific database; and accessibility (the difficulty of finding the optimum path).

5. These assignments of aboutness are never perfect, as information specialists who do original cataloging of books will attest, and the assignment of subject headings to databases of all sorts is a challenge that has long been constrained both physically (limitations to the number of subject headings allowed) and conceptually (unambiguously capturing the many terms related to a topic). Gomez, Lochbaum, & Landauer (1990) have suggested assigning as many terms as possible to improve retrieval--something much more viable in electronic environments.

6. Waltz (1990) reports 4×10^{16} bytes as an estimate of human long term memory capacity, but no one has officially reported running out of memory!

7. Display units include cathode ray tubes (CRTs) that depend on electrons systematically striking phosphorus-coated screens, liquid-crystal panels that require a separate light source and depend on electronic realignment of organic liquid crystals, and electroluminescent displays that depend on thin phosphor layers that allow a thin, flat screen. See Helander (1987) for an overview of visual display technology and human factors.

8. There is a clear trend toward use of multiple I/O devices to enhance interactivity. Multiple I/O devices are the basis for telepresence (virtual reality) and it remains to see how multiple channels of information flow will affect information seeking.

9. Communication systems can be characterized as simplex (source is always the source and the destination cannot reply), half-duplex (both source and destination can send and receive, but must take turns to do so), and full-duplex (both source and destination can send and receive simultaneously).

10. It is interesting to note that most formal instruction is carefully sequenced but discussions are likely to be less well-structured. The benefits of the two instructional strategies in combination may provide some guidance for our thinking about the mix of linear and non-linear presentations in electronic systems.

11. In Chapter 4 it is argued that information-seeking knowledge and skills represent a domain of knowledge.

12. Examples of high performance computing leading to new discoveries in physics, meteorology, and other fields are common (e.g., see Billingsley, Brown, & Derohanes, 1992). Examples of retrieval systems leading to new knowledge include Swanson's use of medical literature retrieval systems to discover new medical knowledge (e.g., he found previously unknown relationships between migraine headaches and magnesium by using bibliographic searches of medical literature to locate common terms or citations in disparate literatures; Swanson, 1991) and scholar's use of the

morphological tools in Perseus to discover new philological insights (Marchionini & Crane, 1994).

13. Problem definition is the first step in Polya's (1957) classic treatment of problem solving through heuristic and deductive thinking. His suggestions for problem definition include: examination of what is known and what are the problem conditions, consideration of whether the problem can be solved, introducing suitable notation, separating and writing down parts of the conditions, and drawing figures.

14. For example, CONIT (Marcus, 1983) includes assistance in selecting a database as well as its primary mission of aiding the online search process; I^3 R (Croft & Thompson, 1987) includes user models and a variety of experts that assist users in conducting search; and CODER (Fox, 1987) takes document structure into account in providing expert search assistance.

15. Main entries for a given document in most large U.S. academic libraries are determined according to an elaborate set of rules published as the Anglo-American Cataloging Rules. In the majority of cases, the main entry for a document is the first author's last name, although many variations are possible.

16. Willett and his colleagues (Willett, 1991) have propose paragraph ranking as an access mechanism for full-text retrieval. Such approaches also offer good opportunities for aiding information extraction as well.