The Information Discovery Framework

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ABSTRACT
This paper continues the movement from technology centered to human centered approaches in the study of tasks that involve finding, understanding, and using information, and tools that support these tasks. The iterative role of information as a stimulus to cognition is considered. The information discovery framework consists of a flowchart of connected human cognitive and digital computer states and processes. The purpose of the framework is to inform the design of tools for finding and using information. Divergent thinking laboratory tasks serve as an evaluation method.

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information seeking, information foraging, berrypicking, divergent thinking, working memory, mental models

ACM Classification Keywords
H.1 [Information Systems]: Models and Principles.

APPROACHES TO INFORMATION

Because the vast and growing amount of information accessible from sources such as the world wide web far exceeds the capacity of human attention, it has become increasingly important to improve our selective access to information that we need. Systems that help us use our burgeoning information resources should be tailored to cognitive needs. Many tasks that depend on finding web-based information have been characterized in terms of information retrieval (IR). IR is a technology, not a human-centered definition of the processes that people experience in their use of information.

Bates develops a "berrypicking approach to search" [2]. Berrypicking is a process of moving from one patch of information to another and gathering relevant resources. She identified important aspects of users' practices while seeking information. Her taxonomy of iterative processes through which users move from one information resource to another includes forward and backward citation chaining. Bates observes that the user's information needs change in response to the information that is found. What her work suggests, without quite making explicit, is that users may need to integrate the important bits of information that come from diverse sources. Our own work focuses on providing representations that facilitate this integration.

As is frequently the case with human computer interaction, it is necessary to blend approaches from cognitive psychology, computer science, art, and design. Information foraging (IF) is a transdisciplinary model of human performance in tasks which require gathering and making sense of relevant information for solving problems and making decisions [13]. The IF perspective considers, as we do, the role of cognition in the experience of searching through very large information spaces.

An approach even more like our own is *information seeking* (IS), "a process in which humans purposively engage to change their state of knowledge" [8]. It connects human cognition with digital computation, in the context of tasks. IS identifies the human cognitive process of iteration in problem definition, as well as in problem solution, which develops in response to information resources. IS also raises the issue of how information resources are represented. A *surrogate* [3, 8] is a representation that stands for a larger information resource, A surrogate is a replacement for an original item, … which gives some description of the item, and how it can be obtained" [3]. Examples of surrogates include entries in catalogues and bibliographic citations. We are struck that the result sets that search engines generate, and end users' sets of bookmarks are both collections of surrogates. We need to discover how to represent surrogates in ways that support cognition in discovery tasks.

The moves from IR to IS and IF began shifting the emphasis toward human processes. IS focuses on people's use of technology to find relevant information in the course of tasks. We continue this shift by focusing inquiry on the cognitive processes and tasks that people engage in of which information is a part. We want to understand how to build human-centered information systems that support discovery processes. For us, forming a query, and even finding the information you need are not tasks in themselves. They are actions the user takes in a context oriented toward having ideas in response to information.

Our approach focuses on the cognitive structures and processes involved in IF and IS, and on how a software system can extend the user's limited cognitive resources to enhance the discovery of relevant information. *Information discovery* (ID) involves browsing through collections returned by search engines, and forming collections of

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relevant results. Information discovery is characterized by iteratively reformulating problems, manipulating representations, and finding solutions. ID often involves integrating multiple information resources. Examples of ID tasks include buying a car, planning a vacation, choosing a thesis topic, and writing a technical paper.

COGNITIVE STRUCTURES

To inform the design of human-centered information systems, the Information Discovery (ID) framework examines interactions of human cognition with digital information in tasks that draw upon information resources while developing ideas. Human cognition and digital information processing bear a clear resemblance to each other. This similarity occurs because digital information processing systems act as extensions of human information processing abilities and patterns. They carry out analogous functions, thereby augmenting human cognitive functions. Some of the more obvious human cognitive functions that have parallels in digital systems include encoding and symbolically representing data from external sources (e.g., perception and pattern recognition), maintaining multiple information units in parallel in a currently active state (e.g., working memory), persistent storage of information (e.g., long-term memory), and the sequential discovery and examination of stored information that meets current needs (e.g., browsing, search and retrieval).

This view of cognition portrays a dynamic system composed of structures and processes. The structures include sensory systems, working memory, long-term memory, and response systems. While these systems support open-ended thinking, they have capacities and limitations that cannot be exceeded. Cognitive processes in the model include pattern recognition, attention, rehearsal, storage, retrieval, and intentional and automatic responding. These processes allow information in one structure to affect another. They provide the means for an almost infinite flexibility in human thought.

The four major cognitive structures have special functions. Sensory systems operate rapidly to record the vast avalanche of stimuli that bombard our senses every moment, but the recordings last only briefly before the next bombardment [20]. Response systems can be thought of as the machinery that carries out intentions and habits, resulting in observable behavior. Long-term memory contains an enduring repository of personally experienced events, factual knowledge, and knowledge of how to do things. Working memory is the structure where conscious awareness occurs. Working memory holds information for less than a minute unless the information is refreshed, and it holds only about 7 ideas at a time, yet this structure is the center of much of our creative thinking [1, 9, 15].

Working memory has one component that can record, remember, and create visual images in the mind, and another that allows us to maintain an awareness of words or other types of spoken information. These two mechanisms allow us to remain consciously aware of visual and verbal information. They serve as slaves to the executive control system, the cognitive structure in working memory that comprehends meanings, forms ideas, makes decisions, and in general, guides our conscious thinking [1].

Much of what we see as conscious activity, involving intentions and deliberate operations, occurs in working memory. Working memory is centrally involved in interpreting sensory input, storing and retrieving information in long-term memory, maintaining information in an active state, solving problems, making decisions, and exerting conscious control over those parts of our bodies that are not being automatically taken care of. The two major limitations of working memory are its limited capacity, and its brief duration. The capacity of working memory is roughly 7±2 units of information [9, 15]. These units have been referred to as *chunks*, or *clusters* of information that are unitized due to practice, meaning, or other structural organizing principles, such as rhyming or shapes. Importantly, the functional capacity of working memory can be extended if one can find organizing principles for creating larger units from the mass of material to be maintained, a process called *chunking*. The duration of working memory is brief, about half a minute or less if the maintained material is not refreshed or updated. This function can also be extended by rehearsal, a deliberate intentional cognitive process that refreshes and updates material in working memory.

The cognitive system that underlies mundane human information processing activities (e.g., memorizing a grocery list or calculating a sum) is the same one that also carries out more creative activities (e.g., composing a symphony or designing a new invention). This principle is fundamental to the creative cognition approach [5, 19], which claims that creativity can be understood in terms of the cognitive structures and processes that give rise to creative ideas and products. The creative cognition approach has roots in computational modeling [10].

FIXATION AND INCUBATION

A good deal of research on creative cognition has focused on the question of what *blocks* or *impedes* the discovery of creative ideas. The common term for such blocks is *fixation*, a persistent lack of progress in creative thinking. Many different types of impediments can cause fixation in creative thinking, including perceptual blocks, inappropriate implicit assumptions, recent encounters with unsuitable examples, and biases and restrictions that come from one's own conceptual knowledge. Each type of impediment features a set of cognitive mechanisms that appear related to fixation. At every level, however, the resultant fixation can be characterized as a state in which perseverance does not result in progress on a problem or task at hand. A commonly cited remedy for fixation, albeit a weak one, has been termed *incubation*, that is, interrupting the fixated process, putting it aside for a while, and returning to it after a break [14, 16, 17, 18]. This period of incubation allows one to return to a problem with a perspective different from the fixated mental set. Another remedy for fixation is the use of *provocative stimuli* [14], stimuli with random-seeming elements, which can change a person's perspective on a problem. The roles of incubation and provocative stimuli are relevant to divergent thinking tasks in ID.

EVALUATION: DIVERGENT THINKING

The convergent thinking tasks that have been used to study IR, IF, and IS systems are not sufficient for studying ID. It is necessary to investigate divergent thinking laboratory tasks. In a *convergent thinking* task, a problem is very explicitly specified, and the criteria for the sought-for solution are very clear. In contrast, a *divergent* task might have several different formulations of problems, and could result in many different valid solutions [5].

By *convergent*, we mean that through the ID task the user finds a single piece of information. The solution is the correct answer to a closed form question, such as, "Who wrote the first paper on focus+context interfaces?" The accuracy of the answers, and the latency, or time to retrieve the answer from the internet are the appropriate measures of performance for convergent ID.

In contrast, *divergent* information discovery tasks quest for many possible answers to open-ended inquiries, such as the question [5, 18], "Give examples of task contexts in which focus+context interfaces would be useful." Divergent thinking tasks are scored with four measures of ideation: fluency (quantity of ideas), flexibility (number of different categories of ideas), originality (statistical infrequency of an idea), and practicality. In addition to these standard measures of divergent thinking, the products of the divergent tasks can also be assessed subjectively by experts on a 5-point scale. The personal consequences of using an interactive system, such as enjoyment of the experience and flow states [4], can also be assessed.

THE PROCESS OF INFORMATION DISCOVERY

The Information Discovery framework is characterized by a flow of information, via an iterative reformulation process, through a sequence of knowledge states. ID begins by forming a sense of desired results. When successful, it eventually results in new discovery. The flow of information through knowledge states involves human cognitive processes and states, in conjunction with digital algorithms and representations (figure 1). Although the discovery process does not necessarily begin with a particular knowledge state, we begin a description of ID with problem or intention formulation. Formulation may begin with a vague description of a problem, or it may include a clearly and thoroughly articulated set of criteria. The human's typical next step is to specify a search query or web site address. In the next knowledge state, the human evaluates the information surrogates and underlying resources returned by the initial query, in the context of the task; s/he may continue to re-evaluate such result sets iteratively. Then, the human works with the digital system to *compose* ("put together" [12]) a satisfactory set of surrogates. This composition of surrogates is used to facilitate formation of *mental models* of the associated information resources, that is, rough, working models that can at least temporarily serve as a setting for discoveries. We hypothesize that manipulating representations of relevant information surrogates influences such mental model formation [6]. Mental models are *runnable*, that is, capable of envisioning what will happen in numerous hypothetical situations. Discoveries can result when mental models are run by participants. Information discovery occurs when one is running a model in a mental simulation, and one notices unexpected relevance of an element, or unexpected relationships among elements of the mental model. This may trigger additional browsing and searching for unanticipated reasons.

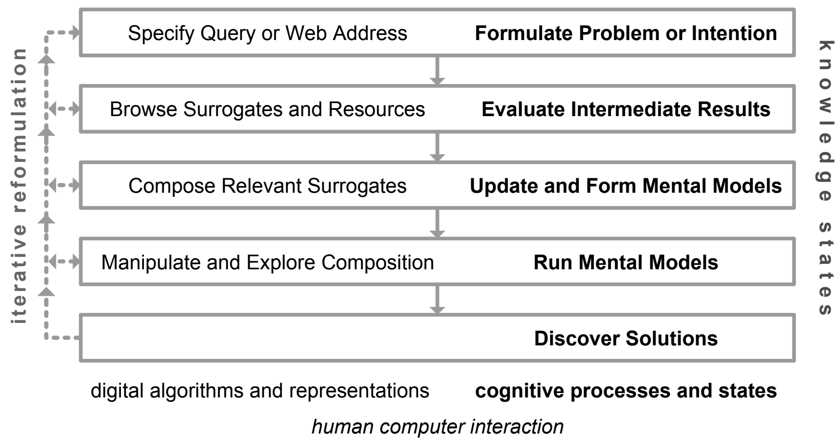

Figure 1: The process of information discovery: knowledge state transformations.

Norman has applied mental models to analyze how humans use interactive systems [11]. In particular he has focused on the gulf between the user's model of a system, and how the system actually works. We are interested in making visible not only how a *system* works, but also models that represent the *information resources* that a human finds and engages with during information discovery tasks.

Figure 2 zooms in to generally describe the process of transformation from any knowledge state in figure 1 to the next. At each stage of the information discovery process, progress is made when a newly transformed state becomes more like a desired knowledge state than it had been before a recent transformation. Sometimes, one may find that the operations one is using to transform a current knowledge state into an improved one are at least temporarily ineffective; no new progress is made in spite of iterative attempts at re-formulation. Such a situation constitutes fixation. It can occur during any step. Software systems can facilitate the transformation of a human's fixated knowledge

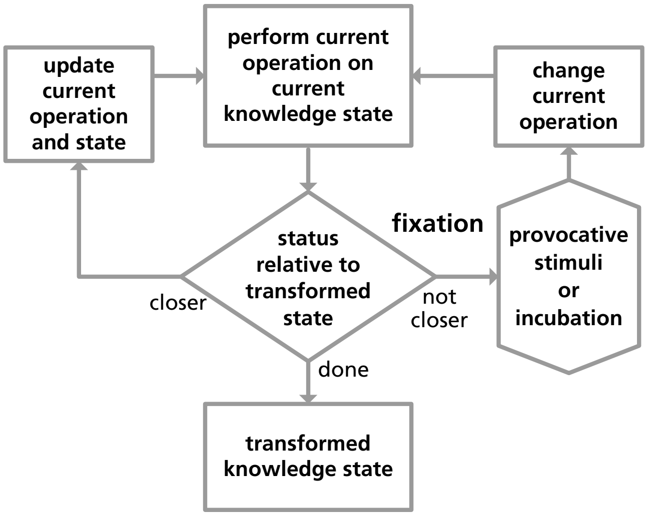

Figure 2: Expanded view of one step of knowledge state transformations in the information discovery process.

state by promoting incubation and providing provocative stimuli. These influences can change the current operations that are being employed at a stage of information discovery, and/or change the current knowledge state. Incubation and provocative stimuli can also move the discovery process back to an earlier step in the process in order to re-formulate it.

IMPLICATIONS FOR DESIGN

Users need affordances that facilitate movement through stages of information discovery, from browsing search results to running mental models (figure 1). Consider applying the process of figure 2 to the later steps of knowledge state transformation in figure 1. The human may initially examine information resources without reaching significant conclusions. In the course of problem or knowledge state redefinition, one must iteratively perform cognitive operations, beginning with the current knowledge state, producing a sequence of knowledge states that get increasingly closer to the desired problem form. In case fixation occurs in this process, incubation and provocative stimuli can overcome it. Human manipulation of information resources and surrogate representations could promote incubation. Or the digital system could get proactively involved. Procedurally generated information compositions of visual surrogates related to the context and task at hand [7] could serve as provocative stimuli that help the user to overcome fixation and achieve discovery.

The Information Discovery framework iteratively integrates human stages of cognition, digital representations, and human interactions, while engaging information resources in the process of advancing human understanding. The human computer interaction involves the digital system acting as a team member in information discovery, supporting and augmenting the user's cognitive processes.

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