Ingrams – A Neuropsychological Explanation for Why People Search

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ABSTRACT

Why do people start a search? Why do they stop? Why do they do what they do in-between? Our goal in this paper is to provide a simple yet general explanation for these acts that has its basis in neuropsychology and observed user behavior. We coin the term "ingram", as an information counterpart to Richard Semon's "engram" or "memory trace". People search to create ingrams. People stop searching because they have created sufficient ingrams, or given up. We describe these acts through a pair of user models and use it to explain various user behaviors in search activity. Understanding people's search acts in terms of ingrams may help us predict or model the interaction of people's information needs, the queries they issue, and the information they consume. If we could observe certain decision-making acts within these activities, we might also gain new insight into the relationships between textual information and knowledge representation.

1. INTRODUCTION

To build better interactive information seeking systems, we need to understand more clearly *why* people search, *how* they formulate search queries, and *what* activities lead them to be satisfied (or not) with the information they choose to consume. It is very challenging to build a comprehensive model of what a person knows, or of what they do not know. However, by observing users directly or indirectly through their long-term and short-term interactions with information seeking systems, we can propose a model for *changes* in knowledge that occur. The model should be consistent with the observed search behavior. By focusing solely on knowledge state changes, our model, while less comprehensive or accurate than more contextually situated models, may prove more amenable to extraction of significant events that can be used as data for machine learning algorithms building text-to-knowledge relationships.

For example, a query such as [olives] provides us relatively little information about the motivation and information need of a searcher. If instead we observe a sequence of queries: [olives]; [when to harvest olives]; [olive picking technique], interspersed by various examined document summaries on the corresponding search results pages and also specific clicked documents, we have a much richer set of data from which to infer the changes in the searcher's knowledge. In Section 3, we name and describe concepts for specific neuropsychological knowledge states that arise throughout the search process.

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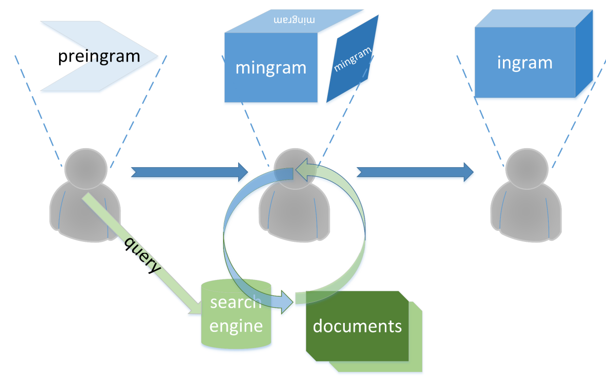

Figure 1 – A successful search process, moving from a preingram via mingrams to an ingram

There are several theories of why or how people search – some of the more influential ones include [2][9][16]. In recent years, the mass availability of effective information retrieval systems coupled with enormous information resources has exploded the amount of information system log data available to researchers in modeling user behavior when searching. Yet because the motivations for any individual search reside within people's minds, it has proven challenging to model these directly from the observable log traces of behavior alone. While user studies have become increasingly sophisticated, with mouse-tracking, gaze-tracking, and physio-logical monitoring, these often place searchers in artificial environments and typically involve carefully curated information seeking tasks. These experimental settings are optimized for gathering data, but do not address the original motivations for search in situ. Alternative ethnographic research studies are more closely aligned with our work, seeking to understand why searchers carry out information search and exploration, e.g. [11]. In Section 4 we consider how our knowledge state changes correspond to a subset of published user behavior models for generalized information search, and the implications for future experiments.

Our contributions in this paper are: (1) provide a simple yet general hypothesis for what neuropsychological *changes* occur in people's minds throughout the course of a search process; (2) align these changes with observed interaction with information seeking systems; and (3) describe decision points and acts of the searcher that could illuminate the relationship between text and knowledge representation as these changes occur, for use by other researchers.

2. RELATED WORK

Taylor's original work on information need is foundational in describing four different levels of cognitive awareness between inception and action within a search process [18]. Taylor's work is more complex than our own in characterizing different levels, but does not proceed to describe subsequent knowledge changes. Like Taylor, Nordlie conducted a comparative study within a library information seeking environment, which suggests dialogue-based interaction might help improve search processes [15]. Nordlie's observations also suggest that the human intermediary must construct (through their dialog with the searcher) their own mental model of the desired goal so they can assist the searcher, a process he describes as "revealment". Belkin et al developed an influential theory of anomalous states of knowledge ASK (that a user comprehends an anomaly in their current state of understanding), akin to the visceral need level of Taylor, and applied it to the task of improving information retrieval systems [2]. Our explanation aligns with this visceral need or anomalous state as a starting neurophysiological frame. Kuhlthau's Information Search Process framework is also influential, describing a 6-stage series of tasks, with associated thoughts, feelings, actions and strategies [9]; we seek a simpler explanation. Pirolli et al developed an Information Foraging model, inspired from anthropological theories of food seeking behavior to describe information seeking [16]; again, this has been influential in our explanation of partially attained states in completion of an information seeking task. Recently Azzopardi proposed an economic theory of user behavior to describe the choices made during searching, hypothesizing that users seek to minimize cognitive load [1]. We see this as primarily an operational explanation of search activity, rather than our focus which is more on changes in information and knowledge acquisition.

3. CONCEPTS

3.1 Ingram

We coin the term "ingram", as an information counterpart to Richard Semon's hypothetical "engram" [17]. In neuropsychology, the engram is a memory trace that has been physically encoded in the brain. Though science lacks a comprehensive understanding of this, it is still useful to hypothesize that there must be some biophysical or biochemical change in the brain to support the encoding and retrieval of a memory.

Just as an engram is an encoding of memory there must be some changes in the brain that occur during information seeking. We propose the ingram as the change in the brain, comprising one or more engrams, that occur during a given information seeking process. The main outcome and motivation for search is a change in knowledge [9][16], and that change as encoded in the brain is an ingram. In programmatic terms we might denote this as:

SearchProcess(Person) → Person', s.t. Person' = Person+Ingram

That is, on successfully completing a search process, a person has now incorporated an ingram within their knowledge memory.

For example, suppose we have an olive tree in our garden, and wish to know when and how best to harvest the olive fruits, yet have never done so previously. Without a lot of trial and error, the olives may go unharvested, or be harvested at the wrong time, or be harvested but damaged. Instead, given access to appropriate search engine technology and assuming that our search process is successful, we subsequently know what months to pick olives and how to avoid bruising them, without ever having picked an olive still. These engrams, as encodings in the brain, constitute the ingram of the olive harvesting search process.

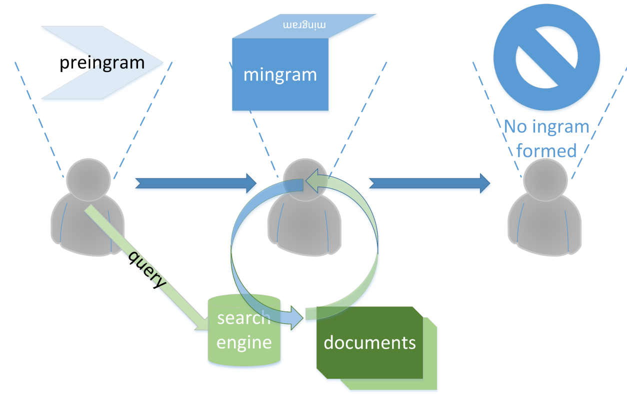

Figure 2 – A partially successful search process, but does not involve creation of an ingram on completion.

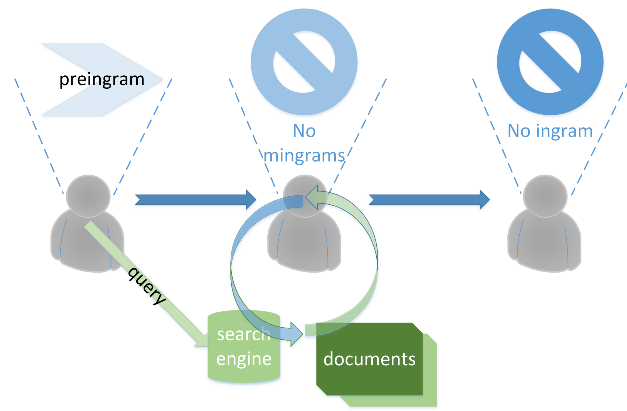

Figure 3 – A completely unsuccessful search process.

3.2 Preingram

If the goal of searching is the ingram, which is a change in the state of knowledge, then prior to searching, people must in some sense be aware of the *need* for an ingram. The awareness of the absence, and the formulation of key characteristics of what the ingram might consist of, must also be present in the mind's knowledge substrate. We term this awareness and formulation of key characteristics of the future ingram a "preingram" (like a premonition of an ingram). Taylor's concept of "information need" [18] and Belkin's concept of an "anomalous state of knowledge" [2] are obviously influential precursors to our preingram.

We propose that people formulate search queries by mapping the key characteristics of a preingram to (typically) a linguistic surface form, in a similar way to how people translate their ideas to language. The precise mapping chosen is conditioned on many different factors, including the person's mental model of how search engines work, the query construction tools provided by the search engines (e.g. query suggestions interfaces), and most importantly, the key characteristics of the ingram that are understood in the preingram.

Returning to our olive tree example, the awareness of needing to know about when the best time to harvest olives, and generalized concepts like "olives", "fruit", "ripeness" "picking", "harvesting" form the corresponding preingram. A natural language expression might be "when is the best time to harvest olives and how should I do it". However, since few search engines are optimally suited to natural language queries, we are more likely to construct a search query similar to [olive picking time] or [when to harvest olives].

3.3 Mingram

While simple search intents (for example, navigational search [3] or refinding activities [19]) may be satisfied by a single query-document pair, many are not. As described by Cole et al [5] while investigating the practical application of Belkin's ASK model for information retrieval [2], there may be an "issue of unknown item information need and the non-specifiability of this sort of need". In fact, it is perhaps even more complex – there are the "known unknowns" that we seek and can partially name when our search process commences, and there are the "unknown unknowns" that we only discover during the process of seeking itself. We believe that a common example of these "unknown unknowns" occurs when searchers acquire vocabulary while reading documents, such that they subsequently employ some of these words as query terms that lead to satisfied search activity. Overall, what we see is that many search sessions require multiple queries and entail extended information discovery and progressive learning [7].

To characterize the partial information accumulation aspect of search processes, we need one additional concept – the "mingram" (like a micro or minimal or most of an ingram). A mingram arises in the searcher's knowledge memory when some useful piece of content is comprehended as part of the information seeking process in order to form the final ingram. Once a sufficient set of mingrams have been assembled, the searcher may determine that the ingram is complete, and cease their search task. Conversely a searcher may be able to assemble a number of mingrams, but still be unable to complete their ingram. At this point, they may either abandon their search altogether, or continue their search process with new queries, browsing, or re-queries. Mingrams have an analog in the relevance measurement domain, being the "information nugget" concept described by Voorhees in the TREC Question Answering track [21], and Clarke et al's work on novelty and diversity [4].

Returning to the olive example, one mingram may represent a document passage stating that that olives are best harvested in the fall or autumn season. Another mingram may be an illustrated document showing that the olives change color progressively, and these colors correspond to levels of acid in the fruit. A final mingram may be a video showing that harvesting needs to be careful, as the fruit will easily bruise, and suggest containers and receptacles that can limit bruising of the fruit. Collectively, these three mingrams then lead to the ingram that was sufficient for the user to conclude the information seeking session.

The three primary search process patterns (success, partial success, and no success) can thus be represented by state diagrams which show the sequencing of preingram to ingram via mingrams, with interactions to a search engine and documents. A successful search process is shown in Figure 1, a partially successful search process is shown in Figure 2, and an unsuccessful search process is shown in Figure 3. Note that these are all relatively simple models, and make no account of interrupted search processes (where they extend beyond a single session) or parallel search processes (where multiple goals are pursued within a single session). Arguably, both of these more complex behaviors can be captured by reducing the activities involved to aggregates of these simple forms.

4. USER BEHAVIOR MODELING

We now turn our attention to how our neuropsychological explanation of why people search corresponds to a couple of search user behavior models. These models have been developed to explain observed user behavior from log-based analysis and gaze-tracking user studies. The decision points described by the models may help us focus on where preingram, mingram and ingrams arise.

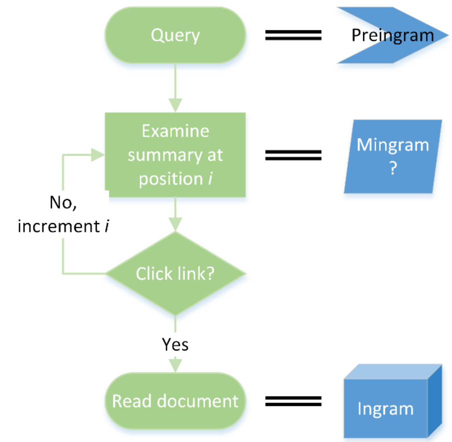

Figure 4 – Cascade model actions and decisions

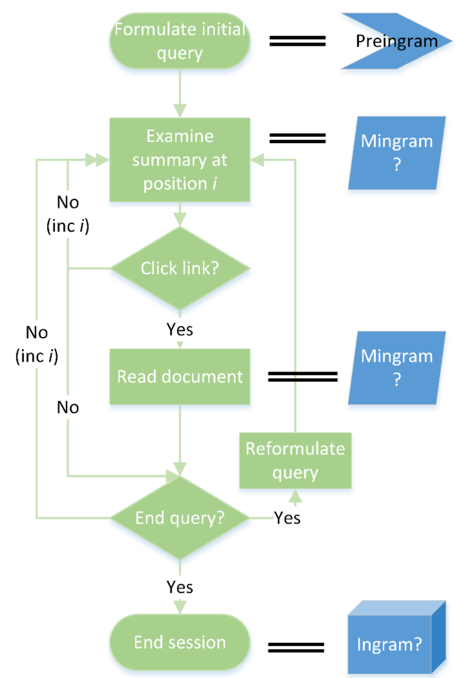

Figure 5 – Behavior model actions and decisions

4.1 Cascade model

The "cascade" model developed by Craswell et al [6] is a simple and influential model that attempts to explain the phenomenon of position bias – that is, that users click on relevant documents nearer the top of a ranked list of results. The model is elegant in its simplicity, suggesting that users traverse a list from top to bottom, examining each document summary, and clicking with a probability proportional to the underlying document's relevance. Once a document is clicked, the searcher does not return, and they are assumed to have found relevant material. The model was the best of four they considered in explaining click patterns in a commercial search engine log. The model does not attempt to describe query reformulation.

In Figure 4, we illustrate the equivalence stages between the simplest cascade model and the ingram explanations. The query is assumed in the cascade model, and the equivalence is a preingram. As the searcher examines each summary, a mingram may (or may not) be created, depending on the content of the summary. Then, after clicking the document, the searcher reads it (and does not return), which corresponds to the creation of the ingram. Ignoring "good abandonment" scenarios [10], we can make a simplifying assumption that the summaries of skipped documents (ones which are not clicked) do not create mingrams at all. The decision to click becomes the critical factor in this model. Deciding not to click means we can ignore these documents. Deciding to click means we need to examine the summary as a candidate for mingram creation, and the full document for both mingram and ingram creation.

4.2 A user behavior-based model

There have been several enhancements to the cascade model. In one of the most comprehensive, recent efforts by Moffat, Thomas and Scholer have focused on using gaze tracking from user studies to understand actual summary examination behavior, document reading behavior, and query reformulations. These observations were used to describe new user models and metrics that may be more aligned to real behavior than some existing relevance metrics [14][20]. In particular, their user model specifically encompasses query reformulations, and also query abandonment independent of having found relevant material.

In Figure 5, we illustrate the equivalence stages between their combined user behavior model (Fig.s 6 and 7 from [14]) and the ingram explanations. We note that this user model is still not quite in alignment with the observed user behavior reported in [20], where the authors found examination of multiple summaries in a "window" of attention prior to clicking. In contrast to Figure 4, we place a question-mark after Ingram, as the user model acknowledges that users may abandon at any time, without being successful, and we align it with the "End session" termination point in the process, rather than the "Read document" activity. We do this in part as it helps us identify the critical decisions in the model. Again, for simplicity we assume that a summary that is skipped does not contribute to creation of a mingram. Summaries that are clicked may create a mingram, as may the clicked document itself. Query reformulation is now seen as a significant act, as it indicates that an ingram has not yet been created. It is only when the search session ends that an ingram may (or may not) have been created; this is a less deterministic outcome than with the cascade model.

5. CONCLUSION

In both the cascade model and the user behavior-based model, the mapping of preingram, mingrams and ingram to the user actions and decisions being made (examining summaries, clicking links and reading documents, reformulating queries) are consistent with the three search processes we described in Section 3. The observable acts of users, and the decisions we can infer are being made by them, in conjunction with our hypothesized neuropsychological changes, provide us with an opportunity to focus future experiments on these critical points within a searcher's information seeking process. Future advances in detecting and understanding brain activities (e.g. [12]) may also enable us to observe these transitions, from preingram to mingram, and from mingrams to ingram. Similarly, characterizing the neuro-physiological changes occurring in searchers' brains throughout a search process may help us more effectively focus the selection and mapping of specific text fragments (queries, result page summaries, document fragments) from user behavior logs for the modeling of knowledge representation via new machine learning approaches involving distributed representations (e.g. [13]). In these approaches, our model's simple but general characterizations for identifying transition points in knowledge acquisition change are preferred to more complex ones.

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