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From Keyword Search to Exploration: Designing Future Search Interfaces for the Web

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Abstract

This monograph is directed at researchers and developers who are designing the next generation of web search user interfaces, by focusing on the techniques and visualizations that allow users to interact with and have control over their findings. Search is one of the keys to the Web's success. The elegant way in which search results are returned has been well researched and is usually remarkably effective. However,

the body of work produced by decades of research into information retrieval continues to grow rapidly and so it has become hard to synthesize the current state-of-the-art to produce a search interface that is both highly functional, but not cluttered and distracting. Further, recent work has shown that there is substantial room for improving the support provided to users who are exhibiting more exploratory forms of search, including when users may need to learn, discover, and understand novel or complex topics. Overall, there is a recognized need for search systems to provide effective user experiences that do more than simply return results.

With the aim of producing more effective search interfaces, human computer interaction researchers and web designers have been developing novel interactions and features that enable users to conveniently visualize, parse, manipulate, and organize their Web search results. For instance, while a simple set of results may produce specific information (e.g., the capital of Peru), other methods may let users see and explore the *contexts* of their requests for information (more about the country, city, and nearby attractions), or the properties that associate groups of information assets (grouping hotels, restaurants, and attractions by their type, district, or price). Other techniques support information-seeking processes that may last weeks or months or may even require collaboration between multiple searchers. The choice of relevant result visualization strategies in new search systems should reflect the searchers and the higher-level information needs that motivate their searches. These examples provide further motivation for supporting designers, who are challenged to synthesize and understand the breadth of advances in search, so that they can determine the benefits of varied strategies and apply them appropriately to build better systems.

To support researchers and designers in synthesizing and understanding the advances in search, this monograph offers a structured means to think about web search result visualization, based on an inclusive model of search that integrates information retrieval, information seeking and a higher-level context of tasks and goals. We examine each of these levels of search in a survey of advances in browsers and related tools by defining search-related cognitive processes and

analyzing innovative design approaches. We then discuss evaluations at each of these levels of search, presenting significant results and identifying both the traditional and novel means used to produce them. Based on this examination, we propose a taxonomy of search result visualization techniques that can be used to identify gaps for future research and as a reference for designers of next generation web search systems.

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1

Introduction

This monograph is for designers thinking about how they might enhance the experience of discovering, exploring and putting to work information they can access over the Web. This monograph is also for researchers who may be interested in how search interaction approaches have developed over the past decade. In both cases, a fundamental question is at play: what else users could possibly need besides Google to search the Web? That's a fair question, and readers of this survey may have the same question. So to tackle that head on, let us agree: Google is really good. For what it does.

Our monograph considers the approaches for exploring information spaces that Google's elegant keyword search cannot do. Over the past decade, research on alternative search paradigms has emphasized Web front ends on single or unified databases. Such work is productive when the designer has the luxury of working with well-curated documents from a single source, but the elegant visualization or well-tailored faceted browser may not scale to the size and diversity of Web-based information, links, scientific data sets, personal digital photos, creative videos, music, animations, and more. So why does keyword search scale? Because (a) huge resources have been thrown at the problem

and (b) textual data have a satisfying and compliant order to it. We hope this monograph shows that the research and evaluations of alternative approaches to data exploration for knowledge building are the best preparation we have for the next generation Web, the Web of Linked Data.

In a little more than a decade the Web has become the default global repository for information. Many factors have contributed to this remarkable result, from the success of the robust technologies that enable its networked connections, to the commercialization of the backbone that enticed business to support and utilize it, to the ease with which ordinary citizens can publish information to it. But perhaps the key technology that took the Web from a useful supplement of current information practice to become the default communication medium is search. Web search, as provided by Google, Microsoft, Yahoo, etc., enables users to find the information they want via the simplest of interaction paradigms: type some keywords into a box and get back an informative result list that is ranked, as if by magic, so that the first results most likely match what we're trying to find.

Search engines automated what was initially a community-based and commercially coordinated Easter egg hunt: category systems were proposed and documents as they were found either by humans recommending them to such sites, or discovered by human trawlers and some early web crawlers, were assigned to categories. The Web was set up like a giant Yellow Pages. Further, before these nascent directories, the Web was explored by the link. As recently as 2004, surfing the Web was still a common trope for browsing the Web, following from link to link, from one site to another. Not unlike blogs today, web sites might publish best new finds on a topic, and away one would go. Only five years later, who "surfs" or presumes to browse "the Web"? It has grown beyond that scale of the surfable, with its pockets of Dark Web and ice caps of Public Web, where so much more than is indexed by search engines is below the visible water line of documents. This growth is itself related to the existence of search: because it **can** be found by search, rather than relying on recommendations alone, it is worth publishing on the Web; indeed it is necessary to publish on the Web. Because conversely, if it cannot be found on the Web, does it exist?

Search as embodied by the text box and keyword has framed our understanding of what the Web is [145]. It has become so ubiquitously associated with the Web that it is difficult to find a web browser that does not have as a default tool, a keyword search box built into upper right of the browser window, right next to the box for the location. In some cases the URL address bar is already polymorphic: acting as either address area or search bar. The prominence of web search based on the fundamental efficacy of keyword search makes it difficult to imagine what an entire monograph on search interaction may be about. It turns out that this elegant paradigm is especially effective for the 1-min search — find the address for Chez Panisse, get a biography of Madame Curie, or locate the home page for a local car rental. But many users have come to the Web for substantive research that takes hours or weeks — find all the songs written about poverty in the 1930s, prove that there are no patents that cover my emerging innovation, or locate the best legal precedents for my brief.

A second motivator for new search strategies is that the next generation web will offer fresh possibilities that go well beyond finding documents by way of keyword search. Hall and O'Hara [69] stress that what we know as the Web today is the Document Web, and not the Web of Linked Data that is imminently upon us. The older Document Web is about the information, readable by us, written by us, and framed for our use. It is this very human-readable orientation of the Web and it is the presentation technologies in the browser that have enabled keyword search engines to become so very good: the words *in* the documents are all a search engine has to go on to find appropriate results. It is because the search engine is searching *in* documents that we get a list of documents back: we may only want a sentence in the middle of a document, but we get the whole thing (the document) back.

By contrast, in the newer Web of Linked Data, often called the Semantic Web, the idea is to give the search engine designers more to work with than making best guesses about what results to return based on keyword frequency and number of pages linked to a document. Imagine if instead of a list of results, the machine simply returned "the answer"? Some queries have specific answers: "mc's phone number at work" or "British obesity rate in 2009?" There may be several sources

for this information, but if they concur, why not just present that result, and give the six places the result occurs? Right now, this kind of search result is not feasible because the Web for the most part does not have consistent tags to indicate what is a phone number or where to find obesity rates. Search engines check if a term requested maps to the term in a document, and does very effective ranking very fast. That is of course an oversimplification of all the sophistication to make that experience as fast and accurate as it appears to be.

The goal of the Web of Linked Data is to have information about information available so that not only can designers provide better, clearer answers to such simple queries about phone numbers and statistics, but also users can resolve questions that are difficult to handle without metadata. Some researchers are conducting intriguing research that attempts to create this metadata automatically to derive semantics from the documents themselves. In this monograph we are less concerned with how metadata becomes available. We are concerned with the question of what designers can do with it, once it exists.

While the power of Semantic Web of Linked Data is that it can enhance large diverse, unorganized, and heterogeneous datasets, the unique affordances also challenge our assumptions about how we access information [176]. As the links between data can be numerous, endless, and of any granularity, the assumptions about carefully structured classifications, for example, breakdown. Similarly, while web searches are typically for web pages, it is not clear whether searching at the data level should return any object [21], specific types of objects [146], object relationships [21, 76], portions of RDF [47], entire ontologies [2, 63], and so on.

Further, as the work on semantically linked data has separated the data from presentation, designers and users are able to represent the data however they like [21]. The flipside, however is that someone, either the interface designer or the end user, has to decide how to represent the data. In summary, the freedom enabled by semantically organized data sets has in turn broadened the options and increased the number of decisions that designers and end users have to make. Recent work has shown, however, that increasing numbers of options can make designers and users feel less confident in their decisions, and less happy

with their results [130, 149], rather than making them feel empowered. What effect, then, does this have on confidence during search interface design, given that designers and users now have more freedom.

These issues are becoming national policy issues, especially as the United States, United Kingdom, and other governments intend to release increasing amounts of information onto the Web as data with sufficient metadata to support more automatic analysis. Metadata tags will indicate that a number represents the reported cases of obesity at a given time and place. The number also has a source and date of creation associated with it so users can verify accuracy and timeliness. It is not simply a number in a document, instead it comes with well-associated meanings.

As soon as this information is available new opportunities for representation beyond document lists become possible. Users will be able to see quickly for themselves: are obesity levels rising at the rates presented in the media, or, by mapping these data from several sources, are they too conservative or aggressive? Imagine being able to look at such sources to ask these kinds of questions with the same facility as we use keyword search now. Now *that* is an interaction challenge.

Designers already offer such representations on smaller than Web scale information sources; that is what most of the literature we will review considers. In that sense we have some preparation for what is to come. But there are also entirely new interaction challenges. There will be many data sources from many places that map to given meanings, like obesity statistics. How can these disparate sources be gathered, inspected, and explored?

Right now, we are on the cusp of a transition from the Document Web to the Document/Data Web. It is an incredible time to be interested in designing or researching how to engage with these immense volumes of data. Are designers and researchers ready for this transition? The findings presented here may act as guideposts for this near future. We may also look back in ten years at these nascent efforts to imagine exploring data at scale and say either that was clever or that was naïve. It will be more than intriguing to see what principles remain, and what have yet to be imagined. In the meantime, we look back in order to leap ahead.

In the remainder of this monograph, Section 2 identifies and explains a model of search that is used to structure the discussion in the following sections and forms the basis of the taxonomy of advances in interactive search. In short, the model describes search in increasing layers of context, from simple retrieval, to broader strategies, and to the wider tasks that motivate them. Section 3 identifies specific advances in interactive search, and prominent examples of their use, organized by the different layers of the model to which they apply. Section 4 explains how advances at each layer of the model have been evaluated. Section 5 then presents the final taxonomy, and identifies areas of relatively little research as potential focal points for future research. For search interface designers, the taxonomy provides a list of potential features to include in designs, describing (a) how they support users, (b) how their support has been evaluated, and (c) how prevalent they have become on the Web.

1.1 A Challenge Faced by Designers of Future Search Systems

Understanding how search interfaces and visualization affect searcher success is a hard challenge, and cannot be as easily measured as speed, document similarity, and result accuracy. In the early 1970s, Cooper [43] suggested that instead of speed metrics, search evaluations should be based on subjective user satisfaction with the results. Later, Robertson and Hancock-Beaulieu [143] noted that the recent, at the time, revolutions of IR research had begun to focus more on users and less on systems. Even more recently, though, researchers have identified just how inadequate the familiar keyword search paradigms, provided by environments such as Google and Bing[1] (Microsoft's search engine), might be for users who need to do more than just find a website that answers a factual question.

The recent focus on these more exploratory forms of search, known as Exploratory Search [172, 174], has identified some search scenarios that require much more diverse searching strategies, including when the

[1] http://www.bing.com

users are (a) unfamiliar with a domain and its terminology, (b) unfamiliar with a system and it's capabilities, or (c) unfamiliar with the full detail of their task or goal. Experts may also conduct demanding searches such as those needing to do: (a) comprehensive searches to find every relevant record (Legal, patent, medical), (b) negation searchers to prove the absence of relevant work (e.g., patent, pharmaceuticals), (c) exception searches to find outlier documents (that take a different or contradictory point of view than commonly held), or (d) bridging searches that connect two disparate fields of study [164]. Exploratory search scenarios are characterized by needs that are "open-ended, persistent, and multifaceted, and information-seeking processes that are opportunistic, iterative, and multitactical" [174]. In each case advances in search need to do more than simply improve the matching of results to terms entered into a single box. Even in the late 1980s, Motro [126] designed the VAGUE interface based on the notion that often, when limited to simple keyword interfaces, users submit numerous evolutions of an original vague query in order to figure out which terms are going to produce all, or even just part, of their desired information.

In many cases, searching involves a range of tactics and techniques, rather than simply submitting a query and seeing a list of matching results. As part of the special issue on Exploratory Search, Marchionini [116] identified, although not exhaustively, a series of strategies that users may often need to employ to achieve their goals, such as comparing, synthesizing, and evaluating. MacKay and Watters [114] present a diary study documenting examples of search tasks that span multiple search sessions, where users return days later to continue on tasks such as job seeking or house hunting. Similarly, Morris [125] has documented the breadth of occasions where users clearly collaborate with family and colleagues on tasks such as holiday planning and team work projects. It is plain to see that a search interface needs to provide more than a simple keyword search form to support users in applying such strategies.

The recognition that there is more to search than basic Information Retrieval has led to many extensions and alternatives to the keyword search paradigm. An example extension is to cluster the results into groups that share attributes [190]. Alternatively, faceted browsing

[75, 168] provides meaningful or significant attributes of web pages to users at the beginning, so that they do not even have to think of words to put in the keyword search box. This can be especially useful in the occasions where people are unfamiliar with a domain and its terminology, for example. These, and many other advances, have much in common and while they each have specific advantages, it is not clear that including them all would provide a stronger search interface. Instead, designers now have the challenge of deciding: (a) what types of search strategies should be supported, if not all of them, and (b) which new features to include in order to support them. This challenge is particularly difficult, when so many advances have been proposed, each with different benefits, and when the benefits of each advance have often been shown independent of others.

1.2 A Taxonomy to Overcome the Challenge

The goal of this monograph is to support designers with this challenge by building a taxonomy of advances in the field of search that can be used as common ground when choosing which features to include within future search interfaces. To build the taxonomy we:

(1) identify a model, produced by theory, which covers the full breadth of search from context and tasks, down to specific actions and results (Section 2);
(2) summarize the specific advances in interactive search (Section 3);
(3) discuss the way that these interactive search advances have been evaluated (Section 4), in accordance with the model of search presented in Section 2; and
(4) present a taxonomy (in Section 5) of the search advances (from Section 3) that takes into account the type of search supported (from Section 2), how the advances have been evaluated (Section 4) and how prevalent they are on the Web.

Producing a structured and consistent taxonomy allows us to compare advances in interactive search, with two benefits. First, the taxonomy can be a reference for designers. The latter half of Section 5

describes a detailed process that designers can apply to systematically decide which features to include in their search designs. As the taxonomy includes advances in the field, their benefits, and how they have been evaluated, a designer can quickly compare options and choose appropriate features for their new interface. Second, the taxonomy can be used by academics to identify areas that require further study and contextualize future advances in the field.

1.3 The Scope of Our Approach

When defining a means of categorizing and communicating existing and on-going research, it is important to define the scope of our approach, so that it is correctly used. Here we specifically bound the content of this monograph in two areas: what we mean by search and what we mean by the Web.

1.3.1 What We Mean by Search

So far, this monograph has used the terms: search, seeking, and Information Retrieval interchangeably. For the rest of the monograph, however, we intend to follow a specific set of terminology, which is defined carefully in the model discussed in Section 2. Information Retrieval is perhaps the most well studied, and so most well-defined term used to describe searching. Typically, Information Retrieval refers to the paradigm where users enter a keyword into a system, which responds by returning the results that are most relevant to the keywords used. This monograph covers a much broader view of search than simply Information Retrieval. Information Seeking is another common term used to describe people's searching behavior, including activities such as searching, browsing, and navigating. Again, however, in this monograph we use the word search in a broader sense than Information Seeking. The model described in Section 2 defines search as the set of activities that take users from identifying a problem all the way to achieving their goals, which will, at times, involve Information Seeking, which in turn, may include Information Retrieval.

1.3.2 What We Mean by the Web

The "indexable web", that is, the portion of the web indexed by major search engines, was estimated at 11.5-billion pages in 2005 [67], with Google reporting that they surpassed the 1-trillion mark in July 2008.[2] One major characteristic of the Web, therefore, is scale. In this monograph, however, search systems are discussed that search both the whole web, and certain domains within the Web and so scale is not always a primary concern for design. A more indicative and remarkable characteristic is the heterogeneity of the contents. The Web contains a variety of data and documents. Documents may be in plain text, HTML, XML, PDF, Rich Text Format (RTF), Microsoft Word (.DOC), spreadsheets, and a multitude of specialized or proprietary formats, including microformats [6]. Multiple forms of media, including still images, audio, and video, are widely available and indexed by general purpose as well as specialized search engines. These documents vary from highly structured databases, to semi-structured web pages, to unstructured text. Again, however, while some web search engines focus on the entire heterogeneous content of the Web, others focus on specific and bounded domains within the Web. In these known and bounded conditions, the format of documents is often known and fixed, and so is not always a concern for all web-based search systems.

In summary, as web search systems are discussed, some are limited by the diversity of online material, and the design of others is motivated by unique features of web collections. Both are important areas that sometimes share concerns but often differ significantly in the challenges they present during the design of search interfaces. An e-commerce site might, for example, try to support searchers with the categorization, price, and availability of their products. Such product-related attributes are not a concern for general Web search, which may includes product results, reviews, specifications, and informational documents. Finally, it is important to remember that as users engage in search, they may be moving between the entire web and known collections within it, in order to achieve their goals.

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