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Offline Evaluation for Information Retrieval

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Abstract

Offline evaluation characterizes an information retrieval (IR) system without relying on actual users in a real-world environment. ★★ Offline evaluation, notably test collection based evaluation, has been the dominant approach in IR evaluation and it is no exaggeration to say that shared evaluation efforts such as the TREC conferences have defined IR research over the years. The reason for this success lies in the ability to compare retrieval systems in a reusable manner.

Several recent trends however necessitate a change in the role and methods of offline evaluation. First and foremost, online search engines with large-scale user base has become commonplace, enabling online evaluation based on user behavior ★★. There are new endpoints for search, such as mobile phones and conversational agents, and the types of search results has diversified beyond a list of web documents to include other result types. Finally, crowdsourcing has provided ways for human judgments of any kind to be collected at a large scale. However, such online evaluation based on user behavior has its own challenges due to repeatability as well the extensive amount of time needed to get online evaluation signals from the users. Furthermore, most smaller companies and academic researchers do not have access to such large scale user base. Hence, recent research in IR evaluation has focused on the advent of new offline evaluation paradigms which are more user-centric, diverse and agile.

This survey aims to provide an overview of recent research in IR evaluation pertaining to the trends above. We first introduce offline evaluation for IR, focusing on how it relates to other evaluation paradigms such as online evaluation. We also overview traditional offline evaluation for IR, and how recent trends have shaped the research so far. We then review research in offline evaluation on three levels: human judgments, evaluation metrics and experiment design. This organization will allow readers to follow recent developments in research from micro-level (human judgment) to macro-level (experiment). Finally, we discuss evaluation practice in industry, which has been a major driving force in research and development in IR.

Paul: This suggests that lab studies are in scope.

Jin: I think it's hard to draw boundaries, except for its goals.

Paul: Doesn't this suggest offline evaluation doesn't matter? Tone this down?

Jin: We'll talk about its limitations later

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1

Introduction

In this chapter, we survey the area and lay conceptual foundations for the rest of the paper. We first provide an overview of different approaches to IR evaluation. We then focus on offline evaluation, explaining traditional approaches and recent trends. Finally, we introduce a conceptual framework and the outline for the rest of this paper.

1.1 Evaluation Paradigms in IR

Evaluating a search system, or any system that supports information access such as recommendation or filtering, is a complex problem. The performance of a search system is dependent on various contextual factors, such as the task at hand, the user's preference, abilities, location and other characteristics, and even the timing of the interaction. Also, the ultimate source of ground truth, the user's judgment, is subjective, volatile, and often hard to come by.

1.1.1 Offline vs. Online Evaluation

In order to meet these challenges, IR researchers have built a rich evaluation tradition. Most of this work has been based on a few simplifying

assumptions. The document collection is static and the user’s information need is represented as a description or a keyword query. The user’s judgments in situ are replaced with judgments collected post-hoc and from third parties, often in the form of binary or numeric-scale labels.

We can define this evaluation paradigm as *offline evaluation* [Sanderson, 2010] in that the evaluation of the system can happen without requiring an actual user. This makes offline evaluation particularly suitable for early-stage evaluation of an IR system, when users are hard to come by. Another typical characteristic of offline evaluation is that the test collection (a set of tasks, judgments and documents) is ‘reusable’, in that once built it can be used to evaluate new systems; because many factors are controlled, evaluations are also commensurable across time and between researchers.

An evaluation paradigm contrasting with offline evaluation is called *online evaluation*. In a recent survey on this topic, online evaluation is defined as the evaluation of a fully functioning system based on implicit measurement of real users’ experiences of the system in a natural usage environment [Hofmann et al., 2016]. That is, online evaluation directly employs user behavior in natural environment for evaluation.

As large-scale online services become commonplace, online evaluation became a viable option for companies who is running service with large user base. In literature, there has been a plethora of papers on methodologies for online evaluation. While online evaluation has benefits in using data readily available as a by-product of serving users, this dependence on user behavior also creates limitations for online evaluation, which we will discuss later in this section.

1.1.2 Hybrid Approaches

So far we have introduced two evaluation paradigms – offline and online evaluation – with distinctive characteristics. Offline evaluation is based on human judges ★, and has strengths in experimental control and reusability. Online evaluation is based on user behavior, and has strengths in fidelity and cost.

While these two approaches comprise the majority of evaluation efforts, there have been several approaches trying to find a middle

Paul: really? How about “...is based on abstractions of real users”?

ground. Click modeling [Chuklin et al., 2015] and counterfactual online evaluation [Li et al., 2015, 2010], for example, re-use online user data for future evaluation. These approaches, while enabling the re-use of online user data, are still limited in that they are based on implicit signals from user behavior. For instance, it is not possible to decide with certainty whether a user indeed found the clicked document relevant or not, even with all the contextual information.

★★

Paul: how is that a limitation? need to be explicit

Jin: I tried to explain

Another related line of work is user study-based evaluation [Bron et al., 2013, Liu et al., 2014, Shah and González-Ibáñez, 2011], which is widely used in interactive IR studies [Kelly, 2009]. In such work, a group of participants are typically brought into a lab environment and asked to perform a set of (usually predetermined) search tasks. It is common for this type of study to collect both behavior and labels from the participants to get a more complete picture of search activity.

User studies bear similarities with offline evaluation in that they typically involve some form of explicit judgments, but their emphasis is more on understanding some aspect of users' search behavior, as opposed to comparative evaluation among search systems. Also, user studies tend to be limited in scale (typically less than 100) and based on subjects non-representative of actual users (typically people within the same institution).

However, the distinctions are getting blurred as search engines increasingly serve more complex set of results, and SERP (search engine results page) or session-level evaluation is drawing more attention. In fact, some recent research has tried to use task completion settings for system-to-system comparison [Xu and Mease, 2009]. Also, crowd-sourcing techniques are reducing barriers in getting access to a large number of subjects with diverse background. We will return to this point in Chapter 2.

1.1.3 When to Use Offline Evaluation

At this point, a reader may ask: when should we use online vs. offline evaluation? While online metrics are certainly valuable and must-have when feasible, there are reasons we may need explicit input from human

	Online	Offline
Pros	<div>Cheap</div> <div>Measure actual user reactions</div>	<div>Fast</div> <div>Easy to try new ideas</div> <div>Amortized Cost</div> <div>Portable</div>
Cons	<div>Need to go live</div> <div>Noisy</div> <div>Slow</div> <div>Not duplicable</div>	<div>Needs ground truth</div> <div>Slow at the beginning</div> <div>"Expensive"</div> <div>Inconsistent</div> <div>Difficult to model how users behave</div>

Figure 1.1: Pros and cons of offline vs. online evaluation

judges.

Figure 1.1.3 summarizes the advantages and disadvantages of on-line vs. offline evaluation. Offline evaluation typically requires access to explicit judgments of relevance obtained from relevance assessors, or judges. Obtaining judgments of relevance is an expensive procedure; hence, online evaluation tends to be cheaper compared to offline evaluation. Furthermore, online evaluation is based on signals that directly come from real users, which can enable us to get a more realistic signal of user satisfaction.

On the other hand, online evaluation requires the need for going online as it is based on signals from real users. First, in initial stages of system development we simply might not have real users to study. Furthermore, small companies and academics may not have access to a large volume of users to be able to collect reliable signals. More importantly, signals obtained from real users tend to be noisy and traces of user behavior are often insufficient to measure a user’s true satisfaction. As an example, let’s take clicks on results for evaluating a search engine. While click is certainly an indication that user is interested in

the result, it is not clear whether the clicked result actually led to satisfaction. Also, click is often concentrated on the top of the page, making it difficult to interpret. That is, the ambiguity and bias inherent in user behavior often make it hard to infer true quality of our products.

Another major problem in online evaluation is that usually a significant amount of usage data is needed before one can reach reliable signals of satisfaction. Hence, online evaluation tends to be very slow, which may not be suitable for evaluating the quality of new methodologies quickly.

Another consideration is the reusability of the data collected. In offline evaluation, typically the label is collected at the level of individual information item (i.e., document) and the system is evaluated by its ability to put more relevant items on top. This means the labels can be reused to evaluate new systems that produce different rankings. By contrast, the data collected from online system is only valid for the evaluation of the system user interacted with, and the data should be collected for every new system to be developed.

Offline evaluation, on the other hand, tends to be fast once explicit judgments of relevance are obtained from relevance assessors. Hence, there is an amortised cost of collecting relevance judgments in offline evaluation but once these judgments are collected, they can be used to evaluate the quality of systems quickly, which makes offline evaluation very suitable for trying new ideas. Furthermore, offline evaluation mechanisms can be used to evaluate the quality of new systems; hence, they tend to be reusable and portable.

One major drawback of offline evaluation is the need for explicit judgments of relevance, or the ground truth. Obtaining relevance judgments tend to be quite slow and expensive. Furthermore, these explicit judgments of relevance tends to come from a relevance assessor, as opposed to the real user of the system. Hence, the assessor may have a different understanding than an actual user as to what document should be considered as relevant. Furthermore, different relevance assessors can also disagree with each other, leading to inconsistencies in judgments. Finally, offline evaluation metrics tend to be based on *models* of user behavior, as opposed to behavior signals obtained from real

users and modelling users can be quite challenging due to the variance in behavior and expectations of real users. Hence, evaluation metrics based on user models may not necessarily reflect user satisfaction.

Given these advantages and disadvantages associated with online and offline evaluation, most large scale companies tend to use a combination of both mechanisms. Offline evaluation mechanisms tend to be used for quickly measuring quality of new methods and the algorithms that show promising results tend to be deployed to some selected subset of real users, using online evaluation mechanisms to make the final decision about the deployment of these algorithms. However, offline evaluation tends to be the primary mechanism used by smaller companies with limited users and academic researchers.

1.2 Offline Evaluation for IR

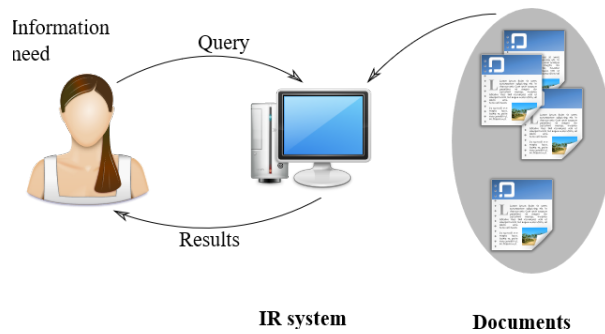
Information retrieval has a rich tradition of evaluation, both online and offline, and this tradition has been responsible for some of the rapid advances in search technology [★](#). Below we survey traditional approaches to offline evaluation, and consider trends in recent years which suggest new roles and methods.

1.2.1 Traditional Approaches in Offline Evaluation

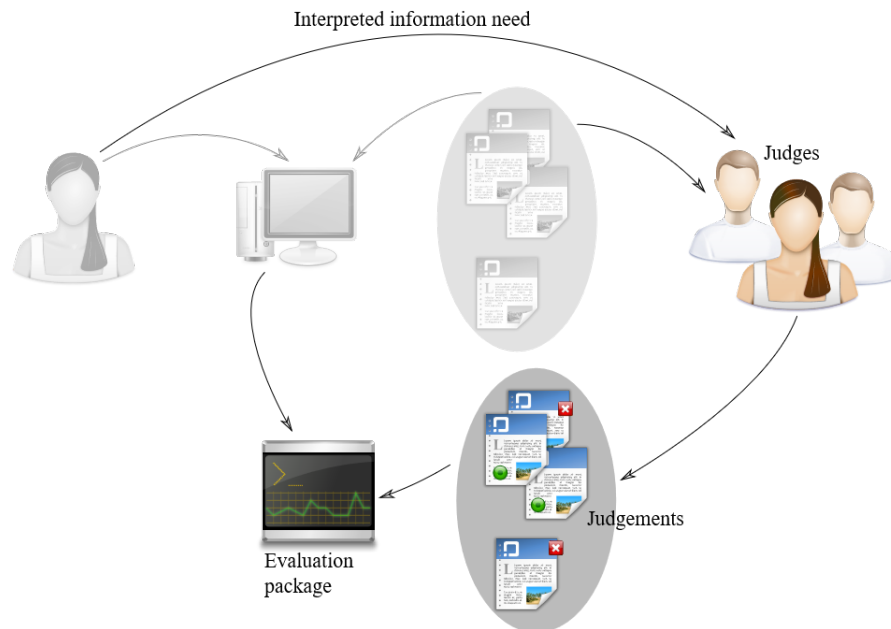
The traditional offline approach to IR evaluation is the test collection, or “Cranfield”, approach first described by Cleverdon [1967] and refined through exercises such as the Text REtrieval Conference (TREC; see Voorhees and Harman [2005] for an overview). We will summarise this approach here, noting that Sanderson [2010] provides a historical summary and comprehensive discussion.

In its most basic form, we can think of an information retrieval system as mediating access to a collection of documents. A user has an information need; they express this as a query; and the system will draw on the document collection to produce some set of results (Figure 1.2a).

The test collection approach simulates this model by using judgements of relevance and evaluation metrics that aim at measuring the quality of the results presented to the user (Figure 1.2b). The query,



(a) A simplified model of a retrieval system in context.



(b) Extension of the model, illustrating third-party relevance judges.

Figure 1.2: Test-collection-based evaluation of an information retrieval system.

document collection, and retrieval system are as before but three components are added:

Judges interpret the user's information need, for example on the basis of the query or other context; and consider the extent to which each document in the collection answers this need.

Judgments record this information obtained from the judges for each (query, document) pair.

Evaluation is then a matter of aggregating the recorded judgements for the set (or ranking) of documents retrieved by the system; or comparing the documents retrieved with the documents judged as relevant.

For example, precision can be calculated by counting the number of retrieved documents which were marked as relevant; recall can be calculated by comparing the number of retrieved documents judged relevant with the overall number judged relevant; or rank-sensitive metrics, such as average precision or reciprocal rank, can look at the judgment for each retrieved document in turn.

Test Collections

The most common approach for evaluating the quality of retrieval systems is the test collection methodology. Forming a test collection typically involves three stages: (1) assembling a document collection, (2) creating a set of information needs (topics) and (3) identifying the set of documents relevant to the topics. We will now describe each one of these stages, the assumptions behind them, and the methods used during each stage. Below we provide a summary of the common mechanisms used in each of these stages.

Shared Evaluation Exercises

real value is from re-use. TREC and related evaluation venues

Relevance

Borlund [2003b]. Recent Morgan and Claypool(?) from Tefko.

1.2.2 Recent Trends in Offline Evaluation

★

Paul: perhaps developments since
TREC got established

So far we have looked at traditional approaches in IR evaluation. While this tradition has served the community well for the past few decades, there has been several trends which necessitates the change in the role and method of IR evaluation. In this section, we outline recent trends and delve into their implications for offline evaluation.

User-Centric Evaluation

First and foremost, online search engines with large-scale user base has become commonplace, enabling online evaluation based on user behavior. This availability of user data has opened up possibilities to validate assumptions of offline evaluation with actual user data. Also, recent work on evaluation metrics Carterette et al. [2011, 2012] have embraced online user data to tune parameters of the metrics.

The overall outcome of this trend is the advent of new IR evaluation paradigms which are more user-centric, diverse and agile. Here, being user-centric means that the evaluation process is based on a model of user behavior, or/and aims to improve user satisfaction or other user-visible measure such as engagement or task completion (Scholer et al. [2013b]).

There has been already new methodologies proposed to better estimate user satisfaction and behavior in judgment collection Verma and Yilmaz [2016], Verma et al. [2016] or metric design Yilmaz et al. [2010], Carterette et al. [2011], Chapelle et al. [2009]. Also, several recent work looked at cross-metric correlation Al-Maskari et al. [2007] Radlinski and Craswell [2010] which aim to align IR evaluation with user satisfaction or some proxy of it.

Diverse Endpoints and Search Scenarios

There are also new endpoints for search beyond desktop web browser such as mobile phone and conversational agents. This opened up a whole venue of research which focuses on different interaction method and user experience in respective endpoints. For instance, mobile device has much smaller screen dimensions and the interaction is based on touch, and conversational agents use natural language, often in voice, to interact with the user.

Even for web search itself, the types of search results has diversified beyond the list of web documents to include other results types such as images, videos, news and even direct answers. This diverse set of results types and user interface design breaks many assumptions of traditional IR evaluation, providing rich opportunities for exploration. In particular, many of these 'answers' can directly satisfy users' information needs on SERP, making it hard to apply click-based evaluation techniques Li et al. [2009] Diriyee et al. [2012].

IR evaluation research has responded to this needs with various lines of work. There has been increased★ interests on whole-page evaluation and optimization Zhou et al. [2012], which encompasses wide variety of page elements beyond web results.

Task and Session-level evaluation Kanoulas et al. [2011a], Carterette et al. [2014b] also drew interests, with TREC tracks of the same name Carterette et al. [2014a]. Finally, there has been a new line of work focusing specifically on mobile interfaces Verma et al. [2016], or evaluation of search with spoken agents Kiseleva et al. [2016].

Crowdsourcing / Agile Evaluation

These diverse new endpoints and scenarios for search required ways to collect labels in a more agile manner, because many of these services are new and exploratory by nature, with less investments compared to well-established ones like web search. Also, in academic setting, it has been difficult to recruit participants with diverse background at scale.

Fortunately, services such as Amazon Mechanical Turk has provided ways for human judgments of any kind to be collected at an large scale.

These services are called ‘crowdsourcing’ in that they pull the wisdom of crowd for tasks human intelligence. Accompanying this new data collection method is the challenge in quality control, since the labeling work is completed by a remote worker on the internet.

Given this opportunities and challenges, there has been quite a few research work Alonso [2012] about how to collect high-quality labels with least efforts. Popular approaches include using overlapping judgments to identify ground truth labels Venanzi et al. [2014], or identifying the quality of judges based on their behaviors Kazai and Zitouni [2016]. We cover some of these methods in Section ??.

1.3 Scenarios for Offline Evaluation

We have outlined basic concepts and recent trends for offline evaluation so far. The goal of this paper is to provide a practical guide in conducting offline evaluation for both academic and industry practitioners. Since there can be various scenarios in conducting offline evaluation, here we outline possible ones which we cover in this paper.

In classical IR research, a typical evaluation scenario is to improve the performance of a system given a test collection and a pre-determined set of evaluation metrics. For instance, in TREC Web Track, participants are given a collection representative of the Web, and then asked to submit the results for their systems in designated format and due date, which then will be evaluated on metrics like NDCG Järvelin and Kekäläinen [2002] or ERR Chapelle et al. [2009].

While academic IR research has developed well-accepted evaluation practice as above, the situation is a lot more ill-defined and varied from practitioners’ standpoint. There are multiple components in a modern IR system such as web search engine, and each requires different emphases and considerations. For instance, one can think of component-level (i.e., query suggestions) evaluation as opposed to system-level evaluation.

Also, building a working system serving real users takes several stages of development. The evaluation at early stages of development would be more exploratory in nature, whereas at later stage the focus

would shift to making ship decisions and so on. We can call the former *information-centric* evaluation in that the goal is to collect information helpful for system development and debugging, where the latter can be considered *number-centric* in that the goal is to get reliable performance numbers for decision making.

Another characteristics of IR evaluation in industry setting is that the evaluation is an on-going process which takes multiple iterations over the lifetime of the service, as opposed to one-off research project. This necessitates the development of so called *evaluation pipeline* where any new system can be evaluation on a ongoing basis.

Since the goal of this paper is to meet the need of practitioners as well as academic researchers, we describe decisions one needs to face in conducting offline evaluation across various scenarios outlined above. We also focus on considerations in designing a evaluation pipeline in industry setting at Chapter 5.

1.4 General Framework for Offline Evaluation

In this section, we describe a general framework for offline evaluation in detail. The goal is to propose a general framework which can encompass diverse set of scenarios outlined above.

1.4.1 Definitions

First, here are a few definitions that will be used throughout this paper. These comprise the components of offline evaluation.

Search Task A search begins with user’s information needs, which we call a search task. Search task can be represented as a description of information needs, or queries user would have used in actual information seeking.

Judging Target Judging target denotes a result produced by an IR system to be evaluated. It can be of any granularity – a snippet, a web document, or entire SERP.

Human Judgment Human judgment is an assessment of *judging target* by a human judge in the context of *search task* over some dimension of quality.

Evaluation Metric Evaluation metric (or metric in short) summarizes judgments into a single score. The design of evaluation metric depends on the type of judgments being collected, and the model of user behavior.

Test Collection A test collection is a collection of judgments with a specific evaluation goal. An evaluation metric summarizes the outcome of an experiment, and an appropriate statistical test needs to be accompanied to make a claim about the validity and reliability of the findings.

★ ★ ★

Emine: I am not sure what an experiment refers to here

Paul: Can we refer to this as an *evaluation*? “Experiment” has a particular meaning; and in particular, (a) we need not be varying anything when doing offline evaluation (so it’s not experimental) and (b) when we do, this measurement/evaluation can be a part of the larger experiment. Calling this an “experiment” is I think wrong, it’s a measurement tool/technique

Jin: I propose calling it *Test Collection*. What do you think?

1.4.2 Evaluation Process

Given the components above, here we discuss the general process for offline evaluation. At a high level, offline evaluation is composed of three steps 1) judgment design 2) metric design 3) experiment design. Alternatively, you can consider the whole process in terms of collecting data (judgments), combining them into meaningful numbers (metrics), build a test collection to drawing conclusions from (test collection). Now we discuss major considerations in each step.

Designing Human Judgments

In the first step, the details of human judgment should be defined, which is the basic unit of offline evaluation. Human judgments capture the quality of the results for given search tasks. Here are major considerations in this step:

1. How do you define and collect search tasks?
2. What should be your judging unit?
3. How do you design judging interface?

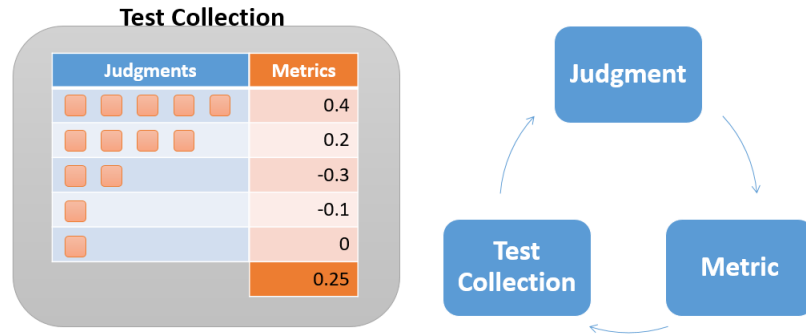


Figure 1.3: Overview of Offline Evaluation.

4. How do you hire and train judges?

Designing Evaluation Metrics

The second step in offline evaluation is selecting or designing a evaluation metric. Metrics summarize the information from individual labels into meaningful numbers. This is essentially the question of how to combine labels to meaningful numbers.

1. How do you transform the labels from human judges?
2. How do you define user models in combining labels into a metric?
3. How do you estimate the parameters for the user model?

Designing Test Collections

Lastly, judgments and metrics should be combined into a test collection to achieve the goal of evaluation. Since this is an iterative step which takes several stages of refinement, here we describe methods and criteria in doing so.

1. How do you size the test collection to fulfill your evaluation goal?
2. How do you evaluate the validity of the outcome?

1.5 The Organization of this Paper

In the following chapters, we describe each process of offline evaluation in detail so that a reader can design his or her own evaluation pipeline following the flow of this paper. Chapter 2 deals with gathering judgments, which need to be created for the purpose. Chapter 3 considers steps in designing an effective metric. Chapter 4 covers the methods in designing and analyzing test collections. Finally, Chapter 5 describes evaluation practices from major companies in search and recommendation area.

★ ★

Emine: We already had a part describing the organization. In general, this section feels a bit repetitive given the text in first page

Paul: I disagree, that was in the abstract; it makes sense here (as well) I think. Unless I missed something?

2

Human Judgments

The goal of collecting a human judgment is to get an accurate measurement of search engine results quality for given set of search tasks. A canonical example is collecting a binary relevance judgment for a document given a TREC-style search topic. The form of human judgment can be quite varied, however, depending on the type of search task and judging target.

We will start with an example to make the discussion more concrete. Figure 2.1 shows a list of possible search tasks about the topic of *crowdsourcing* on the left side, and a few samples from existing web search results for query ‘crowdsourcing’ on the right side.

★ ★ ★

This example presents basic ingredients in collecting human judgments – search tasks and judging targets. From this example one can imagine a myriad of possibilities in designing a human judgment task. You can use either a (potentially ambiguous) keyword query or a well-defined topic description. You can collect judgment for a web document or any SERP element including instant answers or the list of news articles.

The rest of this chapter is to give you guidance in designing a hu-

Emine: Would it be better to show a more standard judging UI here? Like a query and a web page?

Paul: Can we use another topic? We also discuss crowdsourcing below, which may be confusing. Let's use something which is clearly from a user not a researcher, e.g. "rules of soccer". I like the diagram otherwise I think

Jin: @emine we do show judging I/F later. @paul let's keep it this way unless you strongly disagree – i've used this topic throughout the chapter so it's not trivial to change

Search Tasks


What is the crowdsourcing?

What's the best resource to learn crowdsourcing research?

Where can I find recent news on crowdsourcing?

Judging Target

crowd·sourc·ing¹

[ˈkroud.sɔːrsɪŋɡ] 

NOUN

1. the practice of obtaining information or input into a task or project by enlisting the services of a large number of people, either paid or unpaid, typically via the Internet: "crowdsourcing is less expensive than hiring a professional translator" · [\[more\]](#)

Crowdsourcing News, Events, and Resources -- ...

ir.ischool.utexas.edu/crowd ▾

Crowdsourcing News, Events, and Resources. Maintained by Matt Lease and UT Austin's Information Retrieval & Crowdsourcing Lab as a community resource for ...



Scientists are searching for Antarctic seals using satellite imagery—and you can help

Quartz · 3 hours ago

Last night, I went hunting for seals in Antarctica. Well, actually I was sitting in my apartment ...

Siemens Joins JUMP Community to Crowdsourcing Innovation in Building Technologies
Business Wire · 23 hours ago



Figure 2.1: Overview of human judgment collection.

man judgment, in the light of recent literature on this topic. We will look over how to collect search tasks and how to determine a judging target. Various considerations in designing a judging interface will be examined, as well as the methods for finding and managing human judges.

2.1 Collecting Search Tasks

Before considering judgment design, one needs to collect search tasks on which search results will be evaluated. Search tasks represents users' information needs that needs to be satisfied by the search results. In an industry setting where the search engine is used by actual users, the job of collecting search tasks can be as simple as sampling from queries users issued, whereas without access to such resources one needs to create tasks based on assumptions of target users and information needs.

2.1.1 Creating Search Tasks

In many cases one needs to perform offline evaluation without a working system – in building a new product, or in academic setting. It is essential to collect hypothetical search tasks in such cases, which is called simulated search or work (where work includes search and other things) tasks. Borlund [2003a] summarizes the role of simulated work tasks as follows:

A simulated work task situation, which is a short 'cover story', serves two main functions: 1) it triggers and develops a simulated information need by allowing for user interpretations of the situation, leading to cognitively individual information need interpretations as in real life; and 2) it is the platform against which situational relevance is judged. Further, by being the same for all test persons experimental control is provided. Hence, the concept of a simulated work task situation ensures the experiment both realism and control.

‘Task’ can mean different things for different people, and IR literature has long debated over the definition of search task (see Kelly [2009] for a summary). For our purpose, it is sufficient to understand it as the representation of information needs which a human judge can use to perform a search and judge the quality of results. ★ ★

Paul: and/or? Often no searching is done by a judge

The design of search tasks takes a few considerations which can critically affect evaluation results. First, there is the question of where the task is originated from and how much the judge is interested in or knowledgeable about the task, or the corresponding domain. Edwards and Kelly [2016] shows that judges’ interests in the task has effects on how they perceive and perform the tasks. Judges in general had more knowledge on the tasks they were interested in, expected the tasks to be easier, and had higher engagement in terms of time spent. It is also known that (Bailey et al. [2008]) judges’ knowledge of the domain can affect the quality of the outcome.

Emine: Is that the definition of task? May be we should use a more proper definition?

Paul: task ≠ need, but I think this use is blessed by so much past use

Another dimension of task creation is the complexity, which again has many dimensions. Kelly et al. [2015] looked at this problem using a cognitive complexity framework. They found that participants spent more efforts (queries, clicks and time to completion) in performing tasks with higher cognitive complexity (create, evaluate and analyze) than tasks with lower cognitive complexity (apply, understand, remember).

In sum, these results show that the characteristics of search task is an important dimension in designing an offline evaluation. It is recommended to collect information about task characteristics and design experiments accordingly so that one can control the effect of these factors in evaluation.

2.1.2 Sampling Query Logs

Assuming you have a working search engine with real users, it is natural to collect search tasks from query log data. While this is a seemingly straightforward task, there are a few considerations. We outline some below, along with recommendations based on recent studies.

Evaluation Goals The appropriate sampling strategy depends on evaluation goals. In a typical scenario, it is reasonable to start with

Paul: A random sample, you mean?
Deduplicated? Balanced/stratified?

a *representative* sample of the traffic ★. Measurements based on this sampling strategy would lead to the characterization of *average* performance, but there are scenarios where average performance is not informative.

For example, a recent paper from Zaragoza et al. [2010] suggested techniques to identify segments useful for measurement. They introduce the notion of ‘disruptive sets’, which are a set of queries with high quality results in one engine, but not in another. Using a disruptive set, one can focus on the set of queries with a goal to gain competitive advantage.

Other goals can also dictate the choice of sample. For instance, in industry one often targets a specific query segment (e.g., queries with fresh or local search intent); or perhaps on *hard* queries where there is more room for improvement. In these case a sample focusing on the particular segment maximizes the evaluation efficiency.

Characteristics of Search Traffic The characteristics of search traffic also needs to be considered. Baeza-Yates [2015] shows that web search query logs follow a power distribution, with longer tails. He suggests a sampling technique to generate a sample that follows this distribution. The main idea is to bin the queries based on the frequency, which allows the sampled queries to match the distribution of original query set.

Paul: so, stratified and re-balanced?

Jin: more details?

★ ★

Query vs. Task Description While you can ask judges to imagine a search task given a query, it is open to question whether using query to represent an information need is optimal. Unlike search tasks, which should contain sufficient details of user information need, queries in a typical search engine are often abbreviated in form, often ambiguous and/or with typographical errors . ★★

Paul: empty cite?

Jin: any recommended citation? i.e., % of queries with errors

These characteristics of user queries can be a significant source of noise because 1) there can be many query forms for given information needs, as shown by Bailey et al. [2015], and 2) inferring true information needs from queries can be hard. On the other hand, Yilmaz et al. [2014a] argued that the choice of intent description can also cause large

variability in judgment and therefore the judging should be done based on queries.

All in all, despite limitations, user queries are still the most readily available sources of task information, and therefore are widely used for judging search results. One can mitigate the noise and ambiguity of the search query by training judges and presenting possible meanings of the query – i.e., a SERP from a commercial search engine. We discuss this in detail in Section 2.2.1.

2.2 Designing a Judging Interface

Once the search tasks are collected, we are ready to design a system to gather judgments. There are several main considerations in designing a judging interface: we cover these in what follows.

1. How do we describe the context of a search task?
(user location, session history, etc.)
2. What should be the target of each judgment?
(webpage, SERP elements or whole SERP)
3. What should be the scale of judgment?
(absolute vs. relative)
4. What is the quality dimension we want to measure?
(relevance, usefulness, novelty, etc.)

2.2.1 Judging Context

There are many contextual variables that affect user satisfaction with any given search result: users' knowledge and preference, language, timing and location of the search, just to name a few. Even with well-defined search tasks, it is hard to specify all these factors, let alone with terse keyword queries. Providing some of this contextual information to judges can potentially reduce the user-judge gap, thereby increasing the judgment quality. ★

Paul: refs?

The choice of what context to provide depends again on the evaluation goal – what do you want judges to be know about the search task?

For instance, if you think user location is crucial in judging the relevance of results (which is the case in many tasks), you should present the user’s location alongside the query text. Note that, if possible, the location information should be collected along with user queries to get a realistic sample of actual user locations.

Relevance judgments are also affected by what user already did during the session, so it is reasonable to present some part of user session as judging context. Several authors have examined this. Chandar and Carterette [2013] used a document as context, with the goal of collecting judgments when the context document has already been read. They proposed an evaluation framework for novelty and diversity evaluation. Golbus et al. [2014] also experimented with using a document as a context, and found that the metrics based on conditional judgments correlate better with user preference at SERP-level. ★★

While one may assume that adding more and more context can only increase the quality of judgments, it should be noted that more context means more effort for judges in digesting and applying the information. Moreover, more context can increase judging cost by adding a further source of variability. That is, instead of collecting judgment for every search task, now that judgments should be collected for every query and context pairs, which can potentially make the evaluation prohibitively expensive. ★★

Therefore, one should carefully consider the value-cost trade-off in adding the context to a judging task. As an extreme example, Mao et al. [2016] used the entire session as a judging context for collecting judgments on usefulness (as opposed to relevance) and found that usefulness metrics show higher inter-assessor agreement and better correlation with task-level user satisfaction. However, they recommend using usefulness evaluation only for post-hoc analysis of the experiments due to high cost associated with using the whole session as a context.

2.2.2 Judging Target

Judging target defines the basic form of judgment. In what granularity the judgment should be collected (judging unit), and whether the judgment should be given for single item, or a set of items (judgment

Paul: other refs?

Jin: on what?

Paul: but you just suggested sampling e.g. location at the same time; so there'll be a 1:1 mapping query:context. But it's true that if you want to examine the effect of one more variable (market, location, time, ... then you'll need more data)

Jin: Yes, judging based on query+context will add variance, which necessitates more data

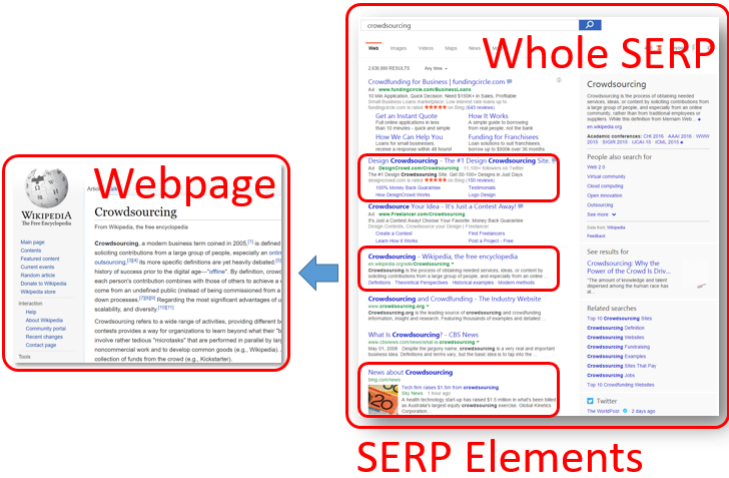


Figure 2.2: Various judging units for web search results.

type).

Judging Unit

Judging unit defines the unit at which judgment should be collected: i.e., in what granularity do we want to collect judgments? In web search, for example, judging unit can be a webpages, SERP elements or a whole SERP, as shown in Figure 2.2.

Basically, judging unit should be determined by the goal of evaluation: if you care about the quality of ranked list, collecting judgment for each web search result seems like a natural choice. If the presentation of SERP is primary concern, SERP should be the right unit for judgment.

On the other hand, if the judging target is reasonably complex with multiple sub-components, it is also possible to collect judgments at smaller unit (i.e., SERP elements) and then calculate scores for large unit (i.e., whole SERP) by combining unit scores in a sensible way. This is how most of IR evaluation metrics (i.e., MAP or NDCG) works.

Now, if we want to collect judgment for SERP, should we collect

element-wise judgments and then combine, or collect single SERP-level judgment? This question can be generalized into the decision of judging unit when the judging target is complex. In fact, there is no hard and fast rule in determining right judging unit, but here we describe a few trade-offs.

Smaller judging unit means simpler judging task which can be faster and more reliable individual judging task. However, the number of judgments to evaluate larger judging unit (i.e., SERP) can be quite high if the judging unit is small, making overall judging cost higher than collecting a single judgment for larger judging unit.

Smaller judging unit also means better reusability of individual labels, because you can combine labels for each SERP element to evaluate arbitrary SERP configuration. This means that the cost of collecting judgments can be amortized over multiple experiments. In fact, query-URL relevance judgment has been so widely used in TREC and other settings because it allows the creation of test collection which can be used to evaluate any ranked list.

On the other hand, smaller judging unit makes an assumption that each label can be collected independent of other element. This is hardly true in a typical search scenario where the concept and criteria of relevance can evolve over time. On this regards, larger judging unit has the benefit of providing rich context for judges. Also, larger judging unit can capture the interaction between elements – i.e., redundancy among documents in a ranked list.

In literature, as briefly mentioned above, document-level judgment is most prevalent. However, there has been a few papers which deal with SERP-level evaluation. Bailey et al. [2010] introduces a judgment scheme which can capture the interaction among SERP elements as well as element-level quality.

SERP-level judgments were introduced in Thomas and Hawking [2006], where they used pairwise judging in order to minimize the complexity of defining judging criteria. (more about this in the following section) Several other works including Kim et al. [2013] refined this idea to include dimensional relevance judgments as well as overall SERP-level comparison. ★

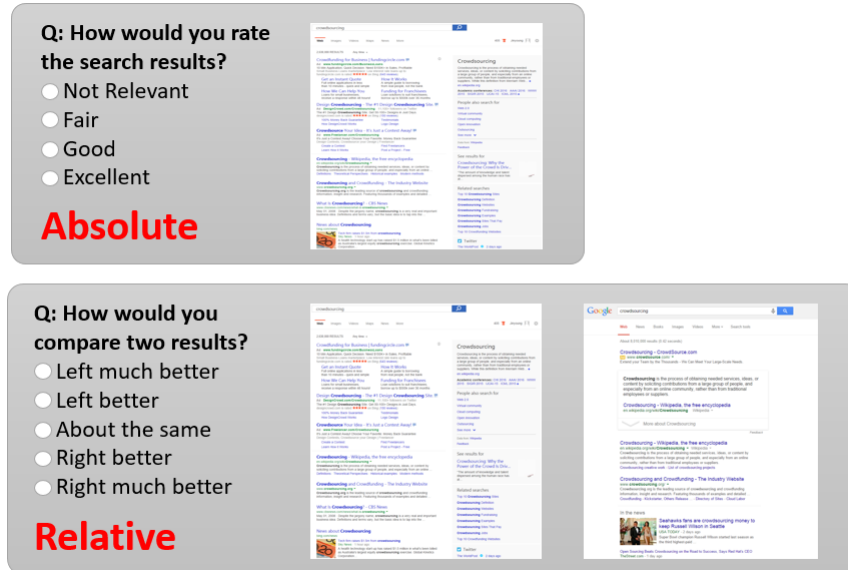


Figure 2.3: Absolute vs. Relative judgments

Absolute vs. Relative Judgment

Another consideration in determining a judging target is the type of judgment, which can be either absolute or relative. In absolute judgment judgment is collected for a single judging target, whereas relative judgment asks for pairwise preference between two judging targets. Figure 2.3 shows two types of judgments in evaluating web search results.

Now, how should one choose between absolute vs. relative judgment? In general, making an absolute scale judgment requires having objective criteria among different levels, whereas relative judgment can avoid the issue. Carterette et al. [2008] also suggested that relative judgment is more accurate for document-level judging. Kazai et al. [2013] also found that a pairwise judging mode improves crowdsourcing quality close to that of trained judges.

Relative judgment has been used in various evaluation settings. Chandar and Carterette [2013] employed document-level pairwise judg-

ing using another document as a context, with a goal of novelty and diversity evaluation. Arguello et al. [2011] also proposed an evaluation scheme for aggregated search based on pairwise preference judgment at element-level. Zhou et al. [2012] used SERP-level pairwise preference judgment as a part of the evaluation framework for aggregated search.

On the other hand, absolute judgments are reusable in that you can compare among any items for which you have item-level labels, whereas you need to collect labels for every pair of items. Therefore, if you want to reuse judgments in a production environment where multiple generations of ranking techniques should be compared against each other, absolute judgment might save the cost in the long run. This is also the reason that TREC has employed absolute judgment since its inception. ★ ★

Paul: Add work by Falk et al. on magnitude estimation

Paul: Add work by Diane et al. on the effect of question mode? Can't remember if this is relevant

2.2.3 Judging Criteria

The central assumption of offline evaluation is that human judges can represent real users, and we often want judges to tell us if the judging target would be relevant to the potential user. However, this is not a trivial task for judges given contextual and multi-faceted nature of relevance. (Borlund [2003a]) Actually, Chouldechova and Mease [2013] reports increased judging quality when done by query owners (users who did the search themselves) compared to query non-owners.

Also, while the concept of relevance is broad, it typically specifies the relationship between an information problem and an object, and is not sufficient to capture the true value of the item in the context of search session. Therefore, it has been argued Belkin [2015] that IR as a field should move beyond relevance to evaluate usefulness in the context of search task. TREC Session track Carterette et al. [2014a] is another movement in the same spirit.

Jin: Relevence seems to subsume usefulness according to Borlund:2003. But Belkin:2015 seems to use a narrow definition of relevance.

★

Recent work have tried to address this problem from multiple angles. The role of user effort and effort-based judging has been proposed Yilmaz et al. [2014b] Verma et al. [2016], where it is shown that effort should be incorporated as an additional factor in human judgment to build retrieval systems that optimize user satisfaction. Golbus et al.

[2014] and Kim et al. [2013] also experimented with multi-dimensional judgment collection, which is useful in finding the relationship between aspects of relevance.

Another thread of work looked at the relevance judgment in the context of other document, or even the whole session. Chandar and Carterette [2013] proposed judging methods for novelty and diversity, where they employed preference-based judgment between document A and B in the context of another document (C). The resulting method has benefit of allowing the evaluation of novelty and diversity without requiring the collection of sub-topical judgments.

Mao et al. [2016] proposed to collect usefulness judgment in the context of whole session. They showed that high relevance by assessors is a necessary but not sufficient condition for high usefulness for users, and that usefulness judgments better correlates with behavioral signals such as click cumulative gains. But since usefulness judgments are costly to collect, they advised the usefulness judgments for use in post-hoc evaluation.

In overall, current literature suggests many ways to set judging criteria for relevance, with different methods having different emphases. If the goal is to focus on query-document relevance, a simple interface as seen at the top of Figure 2.3 will do. However, you can add another document or even whole session history as a context if you want to capture the value of the item in the context of a search task.

2.3 Collecting Judgments

Once you have judging interface, now you need to find judges to work with. There are quite a few options from which you can find judges, but you can roughly put them into three categories. 1) team members who work on the project 2) expert judges who typically sits in-house with the team 3) crowd judges who work remotely and can be reached via platforms like Amazon Mechanical Turk.

How should we choose which option to choose? First, it is recommended to start some judging exercise with the team (Group 1) before outsourcing the judging task, because you need to make sure you pro-

vide high-quality interface and descriptions to get judgments of reasonable quality. But this approach soon hits scalability issues, so we focus on expert judges (Group 2) and crowd judges (Group 3) in this paper.

There has been a few recent work comparing human judges of different characteristics. Bailey et al. [2008] is a classic work where they found that judges' level of expertise on the domain can result in small yet consistent difference on system scores and rankings. Similarly, Chouldechova and Mease [2013] looked at judgments done by query owners (users who did the search themselves) vs. query non-owners, where they concluded that query owners are can distinguish a higher quality set of search results from a lower quality set in a blind comparison.

However, neither finding domain experts nor using queries done by judges themselves are feasible if you need judgments at scale, or need to collect judgments from representative sample from traffic. Typically the options available are either in-house judges with some training or crowd judges. Among these groups, Kazai et al. [2013] found that trained judges are significantly more likely to agree with each other and with users than crowd workers. But when they compared to judgments with clicks from real users, they found that the judgments from trained judges does not show higher agreement with user clicks.

2.3.1 Crowdsourcing Relevance Judgments

Crowdsourcing has an unparalleled benefit in cost and scalability, and it has gathered a lot of attention from research community, and a large body of work has been produced in IR community as well. Alonso [2012] provides an comprehensive survey of research and best practice in this area.

Since aggregating redundant judgments from a group of independent assessors has been standard approach in reducing errors, some of these work have focused on collecting and aggregating redundant labels. Venanzi et al. [2014] proposed a community-based Bayesian label aggregation model which is based on finding latent groups among crowd workers and aggregating labels based on them. Davtyan et al. [2015] proposed using textual similar to aggregate crowd judgments, where

the relevance labels from similar documents are propagated. Companies such as Crowdfunder¹ provide services by which high quality labels are automatically calculated based on redundant judgments.

Another approach in improving the quality of crowdsourced judgments is by improving the judging interface design workflow by which crowd judges work on judging work. This section already dealt with design decisions on judging interface design, and Kazai et al. [2012] provide further guidance in deciding the complexity of judging tasks and the amount of payment per judgment.

Several recent work has investigated workflow design for crowdsourcing. At microscopic level, Shokouhi et al. [2015] and Scholer et al. [2013a] looked at the effect of previous assessment on the quality of current judgment, where they showed that the human annotators are likely to assign different relevance labels to a document, depending on the quality of the last document they had judged for the same query. At macroscopic level, Megorskaya et al. [2015] explored various parameters in designing workflow, where they argued for having a communication channel between judges and the overlap of 3 -5 for production environment.

2.4 Open Issues

So far in this section, we looked at issues in collecting human judgments, and provided guidances based on latest research. However, the problem of search is rapidly evolving and as such emerging are new areas for research. Before moving on to the next topic, here we discuss several open issues.

New Judging Target Most of existing research considers document-level judging. But modern SERP contains rich results beyond documents such as instant answers and multimedia results. Extending document-based judging model into these new judging targets would be an interesting problem. This include judging method for captions, instant answers and rich SERPs with all these elements.

¹<https://www.crowdfunder.com/>

New Endpoints for Search Mobile phone is becoming a standard device for accessing the internet, and recently conversational agent has become a major focus for many tech companies. We still yet to find how this new environment can affect judgment collection. Recent work such as Verma and Yilmaz [2016] and Kiseleva et al. [2016] provide precursor in what needs to change for these new environment.

New Judging Methods Standard judging methods collect labels given a search task and result pair. However, this model may not work in environments where search is highly contextual and personal. Several recent work such as Moraveji et al. [2011] and Xu and Mease [2009] explored task-based judgment collection, where judges perform search given a search engine to make their judgments.

3

Evaluation Metrics

The second step in offline evaluation is selecting or designing a meaningful evaluation metric. This is essentially the question of how to combine labels to meaningful numbers. For traditional IR evaluation where the labels are collected at query-URL level, combining labels to a metric requires quite a few assumptions, or even a user model. In this chapter, we go over the various considerations of IR metric design, as well as the user models behind these metrics. We briefly survey some established metrics but spend more time on recent developments: explicit models of user behavior, deriving metrics from these, and open issues including session-level measurement, dealing with variation, and considering rich SERPs. (20-25 pages)

3.1 Basic IR evaluation metrics

- Metrics based on absolute judgments (e.g. Cooper [1973])
 - Metrics based on preference-based judgments, including e.g. aggregated in-situ side-by-side Thomas and Hawking [2006]
 - Ranking-based metrics (Tau/TauAP)
 - Criticisms: especially reproducibility/replicability

3.2 Metrics based on simple aggregation of labels/qrels

- Set-based: P, R
 - Rank-based: P@ k , AP, RR
 - Criticisms: what tasks and behaviors are modeled here?

3.3 Models of behavior

Evaluation metrics that are based on explicit models of user behavior

- The cascade model and variants
- Weights, the C/L/W framework [Moffat et al., 2013]
- ERR, EBU, GAP, Time-biased gain, etc.
- Weighted precision metrics such as RBP, INST; notion of residual [Moffat and Zobel, 2008, Moffat et al., 2015]
 - α -NDCG, IA metrics, etc.
 - Cost-based/economic models and the prospects of metrics from these
- Session-level metrics Kanoulas et al. [2011b] Järvelin et al. [2008]

3.4 Model fitting

Fit of metrics to models; estimating the distribution of parameters/metric values based on user data

Carterette et al. [2011], Moffat et al. [2013]

3.5 Open issues

Open issues in behavior models and the corresponding metrics

- Whole-page quality
- Caption effects
- Variation between users: behaviors, learning styles, cognitive styles, topic expertise, search system expertise, expectations of the system, query variation, ...
 - Duplication in SERPs
 - Learning (?)
 - Non-traditional tasks and novel UIs

- Choosing between metrics; sensitivity; finding evidence any of them correlates with user behavior or other important dependent variables
- Measuring things outside the SERP: query formulation, source/engine selection

4

Test Collections

Experiments is defined as the collection of labels and metrics defined on top of them. We first look over many considerations in order to design an experiment given a budget and time constraint. We then focus on a set of analyses we can perform once the data is collected, followed by the ways of reporting experimental results. (\approx 15 pages)

4.1 Designing an Experiment

- How to select queries?
 - How many queries? Sakai [2014]
 - How many documents? Carterette et al. [2009a]
 - How to distribute judgment efforts across queries and documents? Carterette et al. [2009b], Yilmaz and Robertson [2009]

4.2 Analysis of Experimental Results

- Survey of research results Sakai [2016]
- Drawing conclusions from metrics
 - Hypothesis Testing Dinçer et al. [2014]

- Comparison of different types of significance tests Smucker et al. [2009]

Various analysis methods

- Power analysis Sakai [2014]
- Failure analysis
- Sensitivity and Reliability analysis Urbano et al. [2013]
- Informativeness (MaxEnt) Aslam et al. [2005]
- ETC Bron et al. [2013] Boytsov et al. [2013] Robertson and Kanoulas [2012]

Reporting results

- Effect sizes and distributions, vs point estimates and p values

4.3 Open Issues

- Reusability for SERP/task-level evaluation
 - Beyond significance testing – bayesian alternatives?
- Reusability / Generalizability of experimental results

5

IR Evaluation in Practice

In this chapter, we review evaluation practices happening in both academia and industry. We first cover evaluation practices from academia, including recent TREC tracks, data generation efforts. We also look at evaluation efforts in related area such as recommendation systems and conversational agents. We then turn to evaluation practices from industry including major players in search and recommendation based on published papers and articles.

5.1 Evaluation Practices from Academia

Emerging TREC tracks

- Task track
- Microblog track
- Live QA track
- Contextual suggestions track

Dataset generation efforts

- Living labs for IR ¹

¹<http://living-labs.net/>

- Data set shared by industry ²

Evaluation in related domains

- Aggregate search Zhou et al. [2013]
- Recommendation systems Gunawardana and Shani [2015]
- Conversational agents

5.2 Evaluation Practices from Industry

How are the practitioners doing? (≈ 15 pages)

- Google ^{3 4}
- Bing ⁵
- Netflix Gomez-Uribe and Hunt [2015] ⁶
- Facebook ⁷
- Pinterest ⁸
- LinkedIn ⁹
- Startups ¹⁰
- ¹¹

Common features: combine online and offline evaluation

- Offline evaluation for early iteration
- Online evaluation for final ship decisions

²http://jeffhuang.com/search_query_logs.html

³How Search Works (Google) <https://www.google.com/insidesearch/howsearchworks/thestory/>

⁴Updating Our Search Quality Rating Guidelines
<https://webmasters.googleblog.com/2015/11/updates-our-search-quality-rating.html>

⁵The Role of Content Quality in Bing Ranking (Bing) <http://bit.ly/1T1BaYN>

⁶The Netflix Tech Blog: Learning a Personalized Homepage
<http://techblog.netflix.com/2015/04/learning-personalized-homepage.html>

⁷Who Controls Your Facebook Feed (Slate) <http://slate.me/1T1BbvU>

⁸Machine Learning at Pinterest <http://www.slideshare.net/HiveData/the-hive-think-tank-machine-learning-at-pinterest-by-jure-leskovec-61383413>

⁹<http://www.slideshare.net/dtunkelang/search-quality-at-linkedin>

¹⁰The Humans Hiding Behind the Chatbots
<http://www.bloomberg.com/news/articles/2016-04-18/the-humans-hiding-behind-the-chatbots>

¹¹10 Data Acquisition Strategies for Startups <http://bit.ly/28IHIC7>

6

Conclusions

In this chapter we conclude this survey by providing the summary of contents so far. We also provide a brief outlook toward the future of offline evaluation for IR.

6.1 Summary

Recap: general Components of Offline Evaluation

- Experiment
- Search Task (Query / context)
- Evaluation Metric
- Judging Method (Interface / rating scale)

6.2 Future of Offline Evaluation for IR

Emerging trends in the tech ecosystem

- Mobile-first: different interfaces and information needs
- Natural-language interaction: Bots and Conversational agents
- End-to-end support for task completion: e.g., restaurant reservation

Future of Offline Evaluation

- Evaluation of search agents (as well as engines)
- Evaluation of various information 'cards'
- Evaluation of end-to-end task completion

Future of Offline Evaluation Research

- Need for Academy-Industry collaboration

References

- Azzah Al-Maskari, Mark Sanderson, and Paul Clough. The relationship between ir effectiveness measures and user satisfaction. In *Proceedings of the 30th annual international ACM SIGIR*, SIGIR '07, pages 773–774, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-597-7. . URL <http://doi.acm.org/10.1145/1277741.1277902>.
- Omar Alonso. Implementing crowdsourcing-based relevance experimentation: an industrial perspective. *Information Retrieval*, 16(2):101–120, 2012. ISSN 1573-7659. . URL <http://dx.doi.org/10.1007/s10791-012-9204-1>.
- Jaime Arguello, Fernando Diaz, Jamie Callan, and Ben Carterette. A methodology for evaluating aggregated search results. In *Proceedings of the 33rd European Conference on Advances in Information Retrieval*, ECIR'11, pages 141–152, Berlin, Heidelberg, 2011. Springer-Verlag. ISBN 978-3-642-20160-8. URL <http://dl.acm.org/citation.cfm?id=1996889.1996909>.
- Javed A. Aslam, Emine Yilmaz, and Virgiliu Pavlu. The maximum entropy method for analyzing retrieval measures. In *SIGIR 2005: Proceedings of the 28th Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, Salvador, Brazil, August 15-19, 2005*, pages 27–34, 2005. . URL <http://doi.acm.org/10.1145/1076034.1076042>.
- Ricardo Baeza-Yates. Incremental sampling of query logs. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '15, pages 1093–1096, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3621-5. . URL <http://doi.acm.org/10.1145/2766462.2776780>.

- Peter Bailey, Nick Craswell, Ian Soboroff, Paul Thomas, Arjen P. de Vries, and Emine Yilmaz. Relevance assessment: Are judges exchangeable and does it matter. In *Proceedings of the 31st Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '08, pages 667–674, New York, NY, USA, 2008. ACM. ISBN 978-1-60558-164-4. . URL <http://doi.acm.org/10.1145/1390334.1390447>.
- Peter Bailey, Nick Craswell, Ryen W. White, Liwei Chen, Ashwin Sathyanarayana, and S. M.M. Tahaghoghi. Evaluating search systems using result page context. In *Proceedings of the third symposium on Information interaction in context*, IiiX '10, pages 105–114, New York, NY, USA, 2010. ACM. ISBN 978-1-4503-0247-0. . URL <http://doi.acm.org/10.1145/1840784.1840801>.
- Peter Bailey, Alistair Moffat, Falk Scholer, and Paul Thomas. User variability and ir system evaluation. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '15, pages 625–634, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3621-5. . URL <http://doi.acm.org/10.1145/2766462.2767728>.
- Nicholas J. Belkin. Salton award lecture: People, interacting with information. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '15, pages 1–2, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3621-5. . URL <http://doi.acm.org/10.1145/2766462.2767854>.
- Pia Borlund. The IIR evaluation model: a framework for evaluation of interactive information retrieval systems. *Information Research*, 8(3), 2003a. URL <http://informationr.net/ir/8-3/paper152.html>.
- Pia Borlund. The concept of relevance in IR. *Journal of the American Society for Information Science and Technology*, 54(10):913–925, May 2003b. ISSN 1532-2882.
- Leonid Boytsov, Anna Belova, and Peter Westfall. Deciding on an adjustment for multiplicity in ir experiments. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '13, pages 403–412, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484034>.
- Marc Bron, Jasmijn van Gorp, Frank Nack, Lotte Belice Baltussen, and Maarten de Rijke. Aggregated search interface preferences in multi-session search tasks. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '13, pages 123–132, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484050>.

- Ben Carterette, Paul N. Bennett, David Maxwell Chickering, and Susan T. Dumais. Here or there. In *ECIR*, pages 16–27, 2008.
- Ben Carterette, Virgiliu Pavlu, Hui Fang, and Evangelos Kanoulas. Million query track 2009 overview. In *Proceedings of The Eighteenth Text REtrieval Conference, TREC 2009, Gaithersburg, Maryland, USA, November 17-20, 2009*, 2009a. URL <http://trec.nist.gov/pubs/trec18/papers/MQ09OVERVIEW.pdf>.
- Ben Carterette, Virgiliu Pavlu, Evangelos Kanoulas, Javed A. Aslam, and James Allan. If I had a million queries. In *Advances in Information Retrieval, 31th European Conference on IR Research, ECIR 2009, Toulouse, France, April 6-9, 2009. Proceedings*, pages 288–300, 2009b. . URL http://dx.doi.org/10.1007/978-3-642-00958-7_27.
- Ben Carterette, Evangelos Kanoulas, and Emine Yilmaz. Simulating simple user behavior for system effectiveness evaluation. In *Proceedings of the 20th ACM Conference on Information and Knowledge Management, CIKM 2011, Glasgow, United Kingdom, October 24-28, 2011*, pages 611–620, 2011. . URL <http://doi.acm.org/10.1145/2063576.2063668>.
- Ben Carterette, Evangelos Kanoulas, and Emine Yilmaz. Incorporating variability in user behavior into systems based evaluation. In *Proceedings of the 21st ACM International Conference on Information and Knowledge Management, CIKM '12*, pages 135–144, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1156-4. . URL <http://doi.acm.org/10.1145/2396761.2396782>.
- Ben Carterette, Evangelos Kanoulas, Mark Hall, and Paul Clough. Overview of the trec 2014 session track. Technical report, DTIC Document, 2014a.
- Ben Carterette, Evangelos Kanoulas, Mark M. Hall, and Paul D. Clough. Overview of the TREC 2014 session track. In *Proceedings of The Twenty-Third Text REtrieval Conference, TREC 2014, Gaithersburg, Maryland, USA, November 19-21, 2014*, 2014b. URL <http://trec.nist.gov/pubs/trec23/papers/overview-session.pdf>.
- Praveen Chandar and Ben Carterette. Preference based evaluation measures for novelty and diversity. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR '13*, pages 413–422, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484094>.

- Olivier Chapelle, Donald Metzler, Ya Zhang, and Pierre Grinspan. Expected reciprocal rank for graded relevance. In *Proceedings of the 18th ACM Conference on Information and Knowledge Management, CIKM 2009, Hong Kong, China, November 2-6, 2009*, pages 621–630, 2009. . URL <http://doi.acm.org/10.1145/1645953.1646033>.
- Alexandra Chouldechova and David Mease. Differences in search engine evaluations between query owners and non-owners. In *Proceedings of the Sixth ACM International Conference on Web Search and Data Mining, WSDM '13*, pages 103–112, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-1869-3. . URL <http://doi.acm.org/10.1145/2433396.2433411>.
- Aleksandr Chuklin, Ilya Markov, and Maarten de Rijke. *Click Models for Web Search*. Morgan & Claypool, 2015. ISBN 9781627056489. .
- C. W. Cleverdon. The cranfield tests on index language devices. *Aslib*, 19: 173–192, 1967.
- William S. Cooper. On selecting a measure of retrieval effectiveness. *Journal of the American Society for Information Science*, 24(2):87–100, 1973. ISSN 1097-4571. . URL <http://dx.doi.org/10.1002/asi.4630240204>.
- Martin Davtyan, Carsten Eickhoff, and Thomas Hofmann. Exploiting document content for efficient aggregation of crowdsourcing votes. In *Proceedings of the 24th ACM International on Conference on Information and Knowledge Management, CIKM '15*, pages 783–790, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3794-6. . URL <http://doi.acm.org/10.1145/2806416.2806460>.
- B. Taner Dinger, Craig Macdonald, and Iadh Ounis. Hypothesis testing for the risk-sensitive evaluation of retrieval systems. In *Proceedings of the 37th International ACM SIGIR Conference on Research & Development in Information Retrieval, SIGIR '14*, pages 23–32, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2257-7. . URL <http://doi.acm.org/10.1145/2600428.2609625>.
- Abdigani Diriye, Ryen White, Georg Buscher, and Susan Dumais. Leaving so soon?: understanding and predicting web search abandonment rationales. In *Proceedings of the 21st ACM international conference on Information and knowledge management*, pages 1025–1034. ACM, 2012.
- Ashlee Edwards and Diane Kelly. How does interest in a work task impact search behavior and engagement? In *Proceedings of the 2016 ACM on Conference on Human Information Interaction and Retrieval, CHIIR '16*, pages 249–252, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-3751-9. . URL <http://doi.acm.org/10.1145/2854946.2855000>.

- Peter B. Golbus, Imed Zitouni, Jin Young Kim, Ahmed Hassan, and Fernando Diaz. Contextual and dimensional relevance judgments for reusable serp-level evaluation. In *Proceedings of the 23rd International Conference on World Wide Web*, WWW '14, pages 131–142, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2744-2. . URL <http://doi.acm.org/10.1145/2566486.2568015>.
- Carlos A. Gomez-Urbe and Neil Hunt. The netflix recommender system: Algorithms, business value, and innovation. *ACM Trans. Manage. Inf. Syst.*, 6(4):13:1–13:19, December 2015. ISSN 2158-656X. . URL <http://doi.acm.org/10.1145/2843948>.
- Asela Gunawardana and Guy Shani. Evaluating recommender systems. In *Recommender Systems Handbook*, pages 265–308. Springer, 2015.
- Katja Hofmann, Lihong Li, and Filip Radlinski. Online evaluation for information retrieval. *Foundations and Trends in Information Retrieval*, 2016.
- Kalervo Järvelin and Jaana Kekäläinen. Cumulated gain-based evaluation of ir techniques. *ACM Trans. Inf. Syst.*, 20(4):422–446, October 2002. ISSN 1046-8188. . URL <http://doi.acm.org/10.1145/582415.582418>.
- Kalervo Järvelin, Susan L. Price, Lois M. L. Delcambre, and Marianne Lykke Nielsen. *Advances in Information Retrieval: 30th European Conference on IR Research, ECIR 2008, Glasgow, UK, March 30-April 3, 2008. Proceedings*, chapter Discounted Cumulated Gain Based Evaluation of Multiple-Query IR Sessions, pages 4–15. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008. ISBN 978-3-540-78646-7. . URL http://dx.doi.org/10.1007/978-3-540-78646-7_4.
- Evangelos Kanoulas, Ben Carterette, Paul D. Clough, and Mark Sanderson. Evaluating multi-query sessions. In *Proceeding of the 34th International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR 2011, Beijing, China, July 25-29, 2011*, pages 1053–1062, 2011a. . URL <http://doi.acm.org/10.1145/2009916.2010056>.
- Evangelos Kanoulas, Ben Carterette, Paul D Clough, and Mark Sanderson. Evaluating multi-query sessions. In *Proceedings of the 34th international ACM SIGIR conference on Research and development in Information Retrieval*, pages 1053–1062. ACM, 2011b.
- Gabriella Kazai and Imed Zitouni. Quality management in crowdsourcing using gold judges behavior. In *Proceedings of the Ninth ACM International Conference on Web Search and Data Mining, WSDM '16*, pages 267–276, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-3716-8. . URL <http://doi.acm.org/10.1145/2835776.2835835>.

- Gabriella Kazai, Jaap Kamps, and Natasa Milic-Frayling. An analysis of human factors and label accuracy in crowdsourcing relevance judgments. *Information Retrieval*, 16(2):138–178, 2012. ISSN 1573-7659. . URL <http://dx.doi.org/10.1007/s10791-012-9205-0>.
- Gabriella Kazai, Emine Yilmaz, Nick Craswell, and S.M.M. Tahaghoghi. User intent and assessor disagreement in web search evaluation. In *Proceedings of the 22Nd ACM International Conference on Information & Knowledge Management, CIKM '13*, pages 699–708, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2263-8. . URL <http://doi.acm.org/10.1145/2505515.2505716>.
- Diane Kelly. Methods for evaluating interactive information retrieval systems with users. *Foundations and Trends in Information Retrieval*, 3(1Ã2): 1–224, 2009.
- Diane Kelly, Jaime Arguello, Ashlee Edwards, and Wan-ching Wu. Development and evaluation of search tasks for iir experiments using a cognitive complexity framework. In *Proceedings of the 2015 International Conference on The Theory of Information Retrieval, ICTIR '15*, pages 101–110, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3833-2. . URL <http://doi.acm.org/10.1145/2808194.2809465>.
- Jinyoung Kim, Gabriella Kazai, and Imed Zitouni. Relevance dimensions in preference-based ir evaluation. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR '13*, pages 913–916, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484168>.
- Julia Kiseleva, Kyle Williams, Ahmed Hassan Awadallah, Aidan C. Crook, Imed Zitouni, and Tasos Anastasakos. Predicting user satisfaction with intelligent assistants. In *Proceedings of the 39th International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR '16*, pages 45–54, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4069-4. . URL <http://doi.acm.org/10.1145/2911451.2911521>.
- Jane Li, Scott Huffman, and Akihito Tokuda. Good abandonment in mobile and pc internet search. In *32nd Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*, pages 43–50, 2 Penn Plaza, Suite 701, New York 10121-0701, 2009. URL <http://portal.acm.org/citation.cfm?id=1571941.1571951>.
- Lihong Li, Wei Chu, John Langford, and Robert E Schapire. A contextual-bandit approach to personalized news article recommendation. In *Proceedings of the 19th international conference on World wide web*, pages 661–670. ACM, 2010.

- Lihong Li, Jin Young Kim, and Imed Zitouni. Toward predicting the outcome of an a/b experiment for search relevance. In *Proceedings of the Eighth ACM International Conference on Web Search and Data Mining*, WSDM '15, pages 37–46, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3317-7. . URL <http://doi.acm.org/10.1145/2684822.2685311>.
- Chang Liu, Jingjing Liu, and Nicholas J. Belkin. Predicting search task difficulty at different search stages. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management*, CIKM '14, pages 569–578, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2598-1. . URL <http://doi.acm.org/10.1145/2661829.2661939>.
- Jiaxin Mao, Yiqun Liu, Ke Zhou, Jian-Yun Nie, Jingtao Song, Min Zhang, Shaoping Ma, Jiashen Sun, and Hengliang Luo. When does relevance mean usefulness and user satisfaction in web search? In *Proceedings of the 39th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '16, pages 463–472, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4069-4. . URL <http://doi.acm.org/10.1145/2911451.2911507>.
- Olga Megorskaya, Vladimir Kukushkin, and Pavel Serdyukov. On the relation between assessor's agreement and accuracy in gamified relevance assessment. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '15, pages 605–614, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3621-5. . URL <http://doi.acm.org/10.1145/2766462.2767727>.
- Alistair Moffat and Justin Zobel. Rank-biased precision for measurement of retrieval effectiveness. *ACM Transactions on Information Systems*, 27(1), 2008. paper 2.
- Alistair Moffat, Paul Thomas, and Falk Scholer. Users versus models: What observation tells us about effectiveness metrics. In *Proceedings of the 22Nd ACM International Conference on Information & Knowledge Management*, CIKM '13, pages 659–668, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2263-8. . URL <http://doi.acm.org/10.1145/2505515.2507665>.
- Alistair Moffat, Peter Bailey, Falk Scholer, and Paul Thomas. INST: An adaptive metric for information retrieval evaluation. In *Proceedings of the Australasian Document Computing Symposium*, 2015.

- Neema Moraveji, Daniel Russell, Jacob Bien, and David Mease. Measuring improvement in user search performance resulting from optimal search tips. In *Proceedings of the 34th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '11, pages 355–364, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0757-4. . URL <http://doi.acm.org/10.1145/2009916.2009966>.
- Filip Radlinski and Nick Craswell. Comparing the sensitivity of information retrieval metrics. In *SIGIR*, pages 667–674, 2010.
- Stephen E. Robertson and Evangelos Kanoulas. On per-topic variance in ir evaluation. In *Proceedings of the 35th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '12, pages 891–900, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1472-5. . URL <http://doi.acm.org/10.1145/2348283.2348402>.
- Tetsuya Sakai. Designing test collections for comparing many systems. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management*, CIKM '14, pages 61–70, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2598-1. . URL <http://doi.acm.org/10.1145/2661829.2661893>.
- Tetsuya Sakai. Statistical significance, power, and sample sizes: A systematic review of sigir and tois, 2006-2015. In *Proceedings of the 39th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '16, pages 5–14, New York, NY, USA, 2016. ACM. ISBN 978-1-4503-4069-4. . URL <http://doi.acm.org/10.1145/2911451.2911492>.
- Mark Sanderson. Test collection based evaluation of information retrieval systems. *Foundations and Trends in Information Retrieval*, 4(4):247–375, 2010. ISSN 1554-0669. . URL <http://dx.doi.org/10.1561/15000000009>.
- Falk Scholer, Diane Kelly, Wan-Ching Wu, Hanseul S. Lee, and William Webber. The effect of threshold priming and need for cognition on relevance calibration and assessment. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '13, pages 623–632, New York, NY, USA, 2013a. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484090>.
- Falk Scholer, Alistair Moffat, and Paul Thomas. Choices in batch information retrieval evaluation. In *Proceedings of the Australasian Document Computing Symposium*, 2013b.

- Chirag Shah and Roberto González-Ibáñez. Evaluating the synergic effect of collaboration in information seeking. In *Proceedings of the 34th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '11, pages 913–922, New York, NY, USA, 2011. ACM. ISBN 978-1-4503-0757-4. . URL <http://doi.acm.org/10.1145/2009916.2010038>.
- Milad Shokouhi, Ryen White, and Emine Yilmaz. Anchoring and adjustment in relevance estimation. In *Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '15, pages 963–966, New York, NY, USA, 2015. ACM. ISBN 978-1-4503-3621-5. . URL <http://doi.acm.org/10.1145/2766462.2767841>.
- Mark D. Smucker, James Allan, and Ben Carterette. Agreement among statistical significance tests for information retrieval evaluation at varying sample sizes. In *Proceedings of the 32nd Annual International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR 2009, Boston, MA, USA, July 19-23, 2009, pages 630–631, 2009. . URL <http://doi.acm.org/10.1145/1571941.1572050>.
- Paul Thomas and David Hawking. Evaluation by comparing result sets in context. In *Proceedings of the 15th ACM CIKM*, CIKM '06, pages 94–101, New York, NY, USA, 2006. ACM. ISBN 1-59593-433-2. .
- Julián Urbano, Mónica Marrero, and Diego Martín. On the measurement of test collection reliability. In *Proceedings of the 36th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '13, pages 393–402, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2034-4. . URL <http://doi.acm.org/10.1145/2484028.2484038>.
- Matteo Venzani, John Guiver, Gabriella Kazai, Pushmeet Kohli, and Milad Shokouhi. Community-based bayesian aggregation models for crowdsourcing. In *Proceedings of the 23rd International Conference on World Wide Web*, WWW '14, pages 155–164, New York, NY, USA, 2014. ACM. ISBN 978-1-4503-2744-2. . URL <http://doi.acm.org/10.1145/2566486.2567989>.
- Manisha Verma and Emine Yilmaz. Characterizing relevance on mobile and desktop. In *Advances in Information Retrieval - 38th European Conference on IR Research, ECIR 2016, Padua, Italy, March 20-23, 2016. Proceedings*, pages 212–223, 2016. . URL http://dx.doi.org/10.1007/978-3-319-30671-1_16.

- Manisha Verma, Emine Yilmaz, and Nick Craswell. On obtaining effort based judgments for information retrieval. In *Proceedings of the Ninth ACM International Conference on Web Search and Data Mining, San Francisco, CA, USA, February 22-25, 2016*, pages 277–286, 2016. . URL <http://doi.acm.org/10.1145/2835776.2835840>.
- Ellen M. Voorhees and Donna K. Harman, editors. *TREC: Experimentation and Evaluation in Information Retrieval*. MIT Press, 2005.
- Ya Xu and David Mease. Evaluating web search using task completion time. In *Proceedings of the 32Nd International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR '09*, pages 676–677, New York, NY, USA, 2009. ACM. ISBN 978-1-60558-483-6. . URL <http://doi.acm.org/10.1145/1571941.1572073>.
- Emine Yilmaz and Stephen Robertson. Deep versus shallow judgments in learning to rank. In *Proceedings of the 32nd Annual International ACM SIGIR Conference on Research and Development in Information Retrieval, SIGIR 2009, Boston, MA, USA, July 19-23, 2009*, pages 662–663, 2009. . URL <http://doi.acm.org/10.1145/1571941.1572066>.
- Emine Yilmaz, Milad Shokouhi, Nick Craswell, and Stephen Robertson. Expected browsing utility for web search evaluation. In *Proceedings of the 19th ACM Conference on Information and Knowledge Management, CIKM 2010, Toronto, Ontario, Canada, October 26-30, 2010*, pages 1561–1564, 2010. . URL <http://doi.acm.org/10.1145/1871437.1871672>.
- Emine Yilmaz, Evangelos Kanoulas, and Nick Craswell. Effect of intent descriptions on retrieval evaluation. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management, CIKM '14*, pages 599–608, New York, NY, USA, 2014a. ACM. ISBN 978-1-4503-2598-1. . URL <http://doi.acm.org/10.1145/2661829.2661950>.
- Emine Yilmaz, Manisha Verma, Nick Craswell, Filip Radlinski, and Peter Bailey. Relevance and effort: An analysis of document utility. In *Proceedings of the 23rd ACM International Conference on Conference on Information and Knowledge Management, CIKM '14*, pages 91–100, New York, NY, USA, 2014b. ACM. ISBN 978-1-4503-2598-1. . URL <http://doi.acm.org/10.1145/2661829.2661953>.
- Hugo Zaragoza, B. Barla Cambazoglu, and Ricardo Baeza-Yates. Web search solved?: All result rankings the same? In *Proceedings of the 19th ACM International Conference on Information and Knowledge Management, CIKM '10*, pages 529–538, New York, NY, USA, 2010. ACM. ISBN 978-1-4503-0099-5. . URL <http://doi.acm.org/10.1145/1871437.1871507>.

- Ke Zhou, Ronan Cummins, Mounia Lalmas, and Joemon M. Jose. Evaluating aggregated search pages. In *Proceedings of the 35th International ACM SIGIR Conference on Research and Development in Information Retrieval*, SIGIR '12, pages 115–124, New York, NY, USA, 2012. ACM. ISBN 978-1-4503-1472-5. . URL <http://doi.acm.org/10.1145/2348283.2348302>.
- Ke Zhou, Mounia Lalmas, Tetsuya Sakai, Ronan Cummins, and Joemon M. Jose. On the reliability and intuitiveness of aggregated search metrics. In *Proceedings of the 22Nd ACM International Conference on Information & Knowledge Management*, CIKM '13, pages 689–698, New York, NY, USA, 2013. ACM. ISBN 978-1-4503-2263-8. . URL <http://doi.acm.org/10.1145/2505515.2505691>.