Report from Dagstuhl Seminar 17092

Search as Learning

Edited by

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Abstract

This report describes the program and the results of Dagstuhl Seminar 17092 "Search as Learning", which brought together 26 researchers from diverse research backgrounds. The motivation for the seminar stems from the fact that modern Web search engines are largely engineered and optimized to fulfill lookup tasks instead of complex search tasks. The latter though are an essential component of information discovery and learning. The 3-day seminar started with four perspective talks, providing four different views on the topic of search as learning: interactive information retrieval (IR), psychology, education and system-oriented IR. The remainder of the seminar centered around breakout groups leading to new views on the challenges and issues in search as learning, interspersed with research spotlight talks.

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1 Executive Summary

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Search is everywhere – it penetrates every aspect of our daily lives and most of us can hardly manage a few hours without resorting to a search engine for one task or another. Despite the success of existing (Web) search technology, there are still many challenges and problems that need to be addressed. Today's Web search engines (often also powering domain-specific and site-specific search) are engineered and optimized to fulfil individual users' lookup tasks. This efficiency, however, also means that we largely view search systems as tools to satisfy immediate information needs, instead of rich environments in which humans heavily interact with information content, and search engines act as intelligent dialogue systems, facilitating the communication between users and content. Web search engines are not designed for complex search tasks that require exploration and learning, user collaborations and involve different information seeking stages and search strategies, despite the fact that more than a quarter of Web searches are complex. In recent years, there has been a growing recognition of the importance of studying and designing search systems to foster discovery and enhance the learning experience during the search process outside of formal educational settings. Searches that lead to learning, are naturally complex. Research progress in this area, however, is slow, with many more open questions than answers. Several critical bottlenecks and major impediments to advancements in the search as learning area exist, including (i) the reliance on small-scale lab studies to evaluate novel approaches which severely limit the diversity of investigable factors as well as the ecological validity and generalizability of the findings; (ii) the lack of awareness among researchers' initiatives in this very multidisciplinary area of work; and (iii) the lack of a shared research infrastructure. The 3-day seminar gathered 26 prominent researchers from the fields of information retrieval, psychology and the learning sciences in order to address the critical bottlenecks around search as learning. The seminar sessions alternated between tutorial-style presentations to learn from each other's disciplines and interactive breakout sessions to find a common ground and address the most pressing issues related to the four big research themes of (i) understanding search as a human learning process; (ii) the measurement of learning performance and learning outcomes during search; (iii) the relationship between the learning process and the search context; and (iv) the design of functionalities and search system interventions to promote learning.

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3 Overview of Talks

3.1 What do learners gain when searching?

Leif Azzopardi (University of Strathclyde – Glasgow, GB)

When searching a person faces many choices and decisions e.g. what to query for, what to examine, when to stop? We have developed many conceptual and descriptive models that describe how people interact and what factors are likely to influence the choices that people make. However, they lack the power to predict how a person will behave or explain how they act. This is where formal, often mathematical, models come into play – and have been reasonably successful in explaining how people search and why they behave they way they do, e.g. Foraging Theory and Economic Theory. The basis of such models, requires the specification of a cost function and a gain function, from which we can determine the optimal search behaviour. I hypothesize that one's search behaviour and performance is indicative of their expertise and how close they are to optimal – and so it would be interesting to evaluate and assess the search behaviours and performance of learners to determine whether this is the case or not. However, this is all premised on the measuring of costs and gain. So what do people, in particular, learners, gain when they search? I argue, that we need to move beyond the notion of binary relevance to modelling and measuring the usefulness/utility/value of the information encountered during the search process.

3.2 Crowdsourcing

Ujwal Gadiraju (Leibniz Universität Hannover, DE)

Crowdsourcing has become an increasingly popular means to acquire human input on demand. Microtask crowdsourcing marketplaces facilitate the access to millions of people (called workers) who are willing to participate in tasks in return for monetary rewards or other forms of compensation. This paradigm presents a unique learning context where workers have to learn to complete tasks on-the-fly by applying their learning immediately through the course of batches of tasks. However, most workers typically drop out early in large batches of tasks, depriving themselves of the opportunity to learn on-the-fly through the course of batch completion. By doing so workers squander a potential chance at improving their performance and completing tasks effectively. In this talk, we propose a novel method to engage and retain workers, to improve their learning in crowdsourced information finding tasks by using achievement priming. We present rigorous experimental findings that show that it is possible to retain workers in long batches of tasks by triggering their inherent motivation to achieve and excel. As a consequence of increased worker retention, we find that workers learn to perform more effectively, depicting relatively more stable accuracy and lower task completion times in comparison to workers who drop out early.

3.3 The user's emotional experience in learning and search processes

Gabriele Irle (Universität Hildesheim, DE)

The central question that motivates my research is, how searchers emotionally experience online information searches and which causes and conditions they consider as significant for their emotional experience during the search. Firstly, the results demonstrate that the individual search topics have a strong influence on the searchers' feelings. Secondly, it is shown that those feelings that refer to the activities within the search process are surprisingly less pronounced, because the online search is considered a routine activity. As a result of these findings, we discussed if the search process is secondary to learners, while they are primarily interested in the subject matter itself. For future research on search as learning, we suggest to differentiate between process emotions, prospective and retrospective emotions as well as social emotions.

3.4 Search as learning – a psychological perspective

Yvonne Kammerer (IWM – Tübingen, DE)

In my talk I gave an overview on the topic "search as learning" from a psychological perspective (specifically an educational and applied cognitive psychology perspective). The focus of psychological research in this field is on using the Internet to learn about complex, conflicting scientific or health-related issues rather than to learn simple facts. Such so-called ill-structured problems do not have a single, definitive solution, but are characterized by conflicting and fragile evidence. Two central processing steps that are typically addressed in this mostly experimental research are (1) the evaluation and selection of search results presented by a search engine, and (2) the comparison and integration of information from multiple websites. Moreover, during both steps source evaluation processes are investigated; i.e., whether, how, and when learners attend to, evaluate, and use information about the sources of documents (cf. credibility assessment). As outlined in my talk, a central goal of psychological research in this field is also to identify and examine factors that might influence the information seeking processes and learning outcomes. Such influencing factors are, for instance, prior topic knowledge or attitudes (i.e., individual variables), task instructions or trainings (i.e., contextual variables), or search tools or interfaces (i.e., resource variables).

3.5 How can SAL studies help search engines

Yiqun Liu (Tsinghua University – Beijing, CN)

As the information needs of Web search engine users become more and more diverse, complex search activities, such as exploratory search and multi-step search, have been identified and considered challenging for current search systems. As the user plays a central role in the highly interactive complex search session, user behavior analysis and modeling is vital for making search engines more effective for learning oriented search tasks. After looking through existing researches in search as learning studies, we believe that three research questions should be focused on: (1) How to model search users' cognitive states. (2) How do users' cognitive states affect search behaviors. (3) What are the implications for search engines. Especially, we believe that the third question is quite important because it is highly related with how we can improve current commercial search engines to support SAL processes.

3.6 SAL – A Information Retrieval (IR) / Interactive Information Retrieval (IIR) perspective

Heather O'Brien (University of British Columbia – Vancouver, CA)

Within interactive information retrieval (IIR), learning has been defined as the acquisition of information for the purpose of changing, augmenting, or reinforcing one's existing knowledge base. Learning is intertwined in the search process: searchers learn through interacting with search tools and multimedia content, and is associated with search tasks that require interpreting, comprehending, and comparing information. Within IIR, "searching as learning" is a burgeoning area, but there are many challenges that need to be addressed. First, there is the issue of measurement in dynamic search contexts. Specifically, there is the question of how to develop and evaluate the utility and robustness of learning measures, and the need to distinguish short- and long-term learning outcomes. Second, designing search systems that support learning is essential, and work in the area of exploratory search has addressed the need for systems to support learning, engagement and discovery. However, these systems must not only allow people to explore information, but must support cognitive and affective learning needs. For example, imagine systems that help searchers save, annotate, and revisit information to manage their cognitive load, or that re-engage them if they become frustrated or confused during the learning process. Lastly, we know little about searchers as learners, and how their goals and cognitive abilities interact with system and content variables to influence learning outcomes. Future work must focus on these and other challenges in order to deepen our theoretical, methodological and applied knowledge and contribution in this area.

3.7 Searching As Learning

Rebecca B. Reynolds (Rutgers University – New Brunswick, US)

My work addresses people's learning with information systems, situated in social constructivist learning theory. In conceptualizing and conducting my research I begin by considering the human actor. I investigate ways in which people engage with one another and human-produced documents, artifacts and products, as they construct and produce ideas, knowledge, understanding and artifacts. Social constructivist learning interventions come in many shapes and sizes; my work considers how the structure of such contexts shape and contribute to learning processes and outcomes. My work is situated in information science as well as the learning sciences. In the learning sciences, scholarly debates have emerged around the effectiveness of inquiry-based learning approaches such as those involving autonomous information-seeking and resource uses, on account of cognitive load (e.g., Kirschner, Sweller, Clark, 2006; Hmelo-Silver, Duncan, Chinn, 2007). My work addresses these issues, as I consider ways to develop instructional affordances that optimize learning potentials in users.

Blended e-learning is becoming more commonplace in K-12 education – those contexts in which students meet face-to-face in classrooms, while also using social and informational affordances made available in online environments such as learning management systems and search engines. In one line of work, I investigate middle school and high school student uses of blended learning affordances, specifically in the domain of computer science education. I study an educational project involving students' design and programming of interactive web games. Students and teachers in this context engage daily in a formal in-school class, using a blended learning information system containing the curriculum: multi-modal tutorials, information resources, sequenced assignments to complete online, social engagement affordances, code libraries and presentation spaces for middle schoolers' work, online social features, etc. I investigate children's motivational and information-seeking dispositions and processes, as well as learning outcomes in this context (Reynolds & Harel, 2011; Reynolds & Chiu 2012, 2013, 2015). My work considers how specific instructional features of a blended e-learning curriculum can be optimized to improve students' information-seeking and knowledge-building processes and outcomes (Reynolds, 2016b). In doing so, I consider the role of a range of resources in the learning context ecology, which in addition to the online system, includes expert peers and teachers in class (Reynolds 2016a). My findings indicate that students vary in their need for structure (2012, 2013, 2016a); a robust blended learning environment for young people's CS education can meet student needs by offering multi-modal resource availability, and when led by an educator with sufficient expertise.

My work also considers generalizability of my findings, to other settings, disciplinary subject domains, and/or user populations (e.g., Chu, Reynolds et al., 2016). I am also exploring reading and literacy levels as a factor in student processing of online informational texts for their productive task completion – like that of designing a game.

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3.8 Information behavior in educational information systems – Teachers searching for lesson preparation

Marc Rittberger (DIPF – Frankfurt am Main, DE)

Searching is one of the main competences with respect to the digitalization of education. In Germany the "Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany (KMK)" states in her strategy "education in the digital world" that searching, processing and curating are main competences needed in education. We think, that one of the consequences for learning may be, that education, e.g. in schools, will change from knowing about things to also know where and HOW to find things. In this context of digitalization the organization of learning environments is changing, e.g. by using open educational resources. In our research we observed teachers searching for lesson preparation and we analyzed several data resources, where teachers are searching for learning materials. Results show, that teachers in German speaking countries demand quite concrete questions in the fields of content, method, or aims of lessons. Questions are less concrete, if teachers have information needs with respect to control, sanctions, or organization of the lesson.

3.9 Search as Learning or Learning by Search

Marcus Specht (Open University – Heerlen, NL)

Searching information is a key component of nearly all human learning processes. Recently the discussion about information literacy has become very popular especially when using web search engines and digital information repositories in educational settings. At the Welten Institute we have been exploring different directions for supporting teachers and learners in search activities. Desktop research is a major search activity being used from primary school to university level. The major elements of search activities include the development of expertise to define the right search terms, evaluate available sources and documents, information integration of different sources and other activities depending on the didactical setting. In the WI we perform empirical research on the development of expertise and information skills and develop models for information skills and optimal design of supporting ICT tooling and instructional design.

For the development of expertise the understanding of a domain structure and the different taxonomies used in the domain are a major difference between experts and novices. This is the starting point for a set of projects where our researchers have been working on the use of taxonomies and classification systems for supporting learners in the use of digital information repositories. The WI has developed different visualisations, tools and technologies for personal and collaborative exploration of big data and information spaces focusing on learning and developing expertise.

In designing tools, technologies and instruction to enable humans to search and explore big data structures and use them in learning the WI contributes to the current and future scenarios for Search As Learning.

3.10 Computational Metacognition

Michael Twidale (University of Illinois at Urbana-Champaign, US)

I am trying to understand the ways that people who seem good at learning technologies (often self-identified as ‘techies’) go about doing that learning, and how that contrasts with people who seem less good at learning technologies (often self-identified as ‘non-techies’). Much of the difference seems to be due to a range of metacognitive strategies, combined with certain attitudes to technology learning and the absence of certain misconceptions about technology learning. A critical set of Computational Metacognitive strategies seem to revolve around techniques for searching for information, help and insight that can further the desired technology learning and overcome problems and confusions. These techniques help address challenges of how to search for something when you don’t know what it is called, how to assess the quality of results and their usability, usefulness and appropriateness for one’s level of understanding of the domain (complete but bewilderingly complex answers may be worse than superficial, limited but comprehensible tech fixes), how to handle complex goalstacks of levels of prerequisite actions and knowledge, and how to tailor partial solutions to address the actual problem at hand. The goal is to design pedagogies, interfaces and functionality to enable a much broader proportion of the population acquire the skills to better manage their own learning of technology.

3.11 Looking for "Listening" Online: A Learning Sciences & Learning Analytics Research Project with Potential Implications for Studying & Supporting Search as Learning

Alyssa Wise (New York University, US)

This presentation overviews the notion of online listening as a vehicle for examining how learners attend to the contributions of others in online spaces; this is part of an effort to broaden our understanding of the process of learning through dialogue (with others, potentially also with resources) in technology-mediated environments. Online listening is defined as the collection of behaviors learners engage in as they interact with the existing posts in a discussion forum; it is specifically differentiated from the act of lurking (which implies a lack of subsequent contribution).

Drawing on five years of research conducted through the E-Listening research project, the presentation includes a (re)conceptualization of the notion of listening for online spaces; an explanation of a theoretical taxonomy for considering different kinds of listening in online discussion; documentation of empirical findings about both the specific patterns of listening in which students engage and their the relationships of these to subsequent contributions; the design of a novel graphical interface to support more productive online listening behaviors; and finally the provision of learning analytics on online listening activities to students to support their self-regulation of such. Collectively, results indicate that online listening is a useful concept for investigating the ways learners interact with existing posts in online discussions and for designing technological and pedagogical interventions to support more productive participation. Parallels to notions of search and learning and the potential implications for studying and supporting this process are discussed.

3.12 Dynamic Information Retrieval Modeling

Grace Hui Yang (Georgetown University – Washington, US)

Many modern IR systems and data exhibit characteristics which are largely ignored by conventional techniques. What is missing is an ability for the model to change over time and be responsive to stimulus. Documents, relevance, users and tasks all exhibit dynamic behavior that is captured in big data sets (typically collected over long time spans) and models need to respond to these changes. Further to this, advances in IR interface, personalization and ad display demand models that can react to users in real time and in an intelligent, contextual way. This talk provides an introduction to Dynamic Information Retrieval Modeling. In particular, I talk about how we model information seeking as a partially observable Markov decision process. I also talk about the TREC Dynamic Domain Track.

3.13 Challenges in Measuring Knowledge State Change during Search Sessions

Ran Yu (L3S Research Center – Hannover, DE)

Search systems to date have been viewed more as tools for the retrieval of content to satisfy information needs, than as environments in which humans interact with information content in order to learn. There are more and more research works focusing on improving the learning experience and efficiency during search sessions, however, the measurement of a user's knowledge gain is a common challenge that has not yet been addressed.

In the SoA works, in order to evaluate their approach, the researchers limited their experiment to a few (usually 1-3) very specific predefined topics. Afterwards, they measure the knowledge gain by conducting a small scale quiz or questionnaire. This has limited the scope as well as the contribution of the works.

In a recent project, we focus on measuring knowledge gain during learning related search sessions based on the search activities. This can potentially provide a way to conduct real time evaluation of learning performance without requiring users to provide extra information. This can benefit the works for SAL optimization. This talk is about the challenges that we have encountered in this project, which includes the identification of learning activities, the modeling of knowledge gain and the lack of open data.

4 Working groups

4.1 Working Group Summaries

Kevyn Collins-Thompson (University of Michigan – Ann Arbor, US), Preben Hansen (Stockholm University, SE), and Claudia Hauff (TU Delft, NL)

The following summaries were produced from all working groups. Each group's discussion revolved around a central question, stated at the top of the summary. At the end of each discussion, the group listed challenges and opportunities for future work.

4.2 Understanding search as a human learning process: when and how does learning occur in the search process?

Participants: Heather O'Brien, Christa Womser-Hacker, Soo Young Rieh, Alyssa Wise, Gabriele Irle, Ran Yu, Dan Russell, Rebecca Reynolds, Claudia Hauff.

Introduction

Few empirical studies exist (e.g. [2, 3, 1]) that attempt to quantify when and to what extent learning occurs during the search process. These studies were a starting point for our discussion as they showcase some of the challenges we face in our quest to understand when and how learning occurs in the search process. As this breakout group was the first of the seminar, it covered a wide range of topics and identified a wide range of challenges, not all of them strongly connected to the initial question.

Challenges

1. Different types of learning (procedural vs. declarative) and different learning contexts (structured vs. unstructured, formal vs. informal, incidental vs. intentional) exist. Investigating the impact of search in these circumstances and disentangling those is likely to require different evaluation metrics that are designed specifically for each type and context. It is an open question whether the currently employed proxies (such as measuring the broadening of the vocabulary used in the searches) is a sufficiently clean signal to measure learning.
2. Is it possible to measure to what extent robust learning (learners achieving a deep conceptual understanding) or transfer learning (learners employing learnt concepts in novel situations) is taking place during the search process?
3. Search query logs offer a very limited view into users' minds; we have to make educated guesses on their learning intent, their prior expertise and their context based on noisy signals. In order to make strides into understanding learning we require large-scale data with more semantic meaning behind it. How would such data look like and how can we collect it at scale? This challenge also ties in with the question whether search should be at the centre of the investigation or 'just' one block in the ecology of learning?
4. How can we help users that want to learn something but already struggle early on in the search process when formulating an initial query based on their information need? A common use case here are medical inquiries with users querying for symptoms in laymen terms ("pain in my side") .
5. In the formal learning setting the instructor plays an important role. Does the instructor also have a role in the search as learning setting and if so, how can that role be supported algorithmically or on the search interface level?
6. In formal learning, scaffolding (the learning material is broken down into pieces and a structure is imposed on each piece) is an important part of lesson design. Is it possible to design automated scaffolding tools into the search process? While one could consider query autocompletion and query suggestions as already existing scaffolds, they do not provide sufficient guidance to the learner.
7. What impact does evolving knowledge (Is Pluto a planet? How many moons does Saturn have?) have on search as learning? How can we support users that are searching for information with search requests that are already providing a certain answer frame (e.g. "vaccinations are bad", "climate change is not real")?

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4.3 What is the relationship between the learning process and the context (educational, work-related, etc.) in which learning & searches occur?

Participants: Michael Twidale, Yiqun Liu, Ujwal Gadiraju, Grace Hui Yang, Marc Rittberger, Marcus Specht, Dirk Ahlers, Kevyn Collins-Thompson.

Introduction

Understanding the context of information requests can be critical to interpreting and satisfying them correctly, particularly to support learning. This discussion explored the following themes, beginning with how to characterize and identify "context" in the first place, to methods for getting a more complete picture of a learner's contexts, and the relationship between context and learning.

Issues

How to characterize the dimensions of context. Those mentioned included location, time, task and workflow stage, intention, user characteristics (role/persona, background knowledge, demographics like age, prior knowledge, user history), environmental/machine/resources available, relationships with people and organizations – and the basic questions who, what, where, when, why, and how. Also discussed was the idea of developing a shared open taxonomy of context definitions, for research study definition, evaluation, and application purposes.

Getting a more complete, continuous picture of context for learning. A recurring theme was the problem that currently, search algorithms see only a very limited amount of contextual information (e.g. during the time a user interacts with an online system, such as previous queries in a session) which might limit their ability to find the right information for a learning need. For example, would it help to know more about what a person did before or after they went online? How could a system obtain a more complete picture of a user's continuous, multi-faceted context throughout the day, and connect these with the many different tasks per day? Another key problem in this area is how to tease apart multiple overlapping types of context. There was disagreement as to whether priority should be given to explore the promise of new sensors or signals to fill in these gaps, versus focusing on better processing and integration of existing signals that we already have. The question was also raised: how much context is actually necessary for each task? Can we get context from mental state, and distinguish conscious vs subconscious intent? One suggestion was that an important case of informative contexts were those requiring deep understanding of higher-level scenarios, such as stressful situations, or social atmosphere, where a little information can go a long way.

The relationship between context and learning. Participants noted the importance, and challenge, of matching the learning task to the appropriate context(s), and identifying which contexts were more or less supportive of learning. Sometimes, there is no explicit or conscious learning goal, and content might help identify these cases. A recurring theme was the need to identify the desired learning outcomes that are associated with various activities in context. In fact, the actual learning might happen later, after a user leaves a particular context. Related to theories of situated learning, and the problem of defining the context/situation that something is relevant, we noted as an example of work in learning/context interaction, and cross-context learning, work such as that described in the STELLAR RTST Trend Report on Contextualisation [3], e.g. with applications in language learning: distributed scenarios (integrate situations, devices). Other related work included personalized academic search [2] and information access by professionals in workplace settings [1].

Opportunities

The discussion ended with participants answering a hypothetical question of what research direction they would explore in this area if given a large research award. Some ideas mentioned included the following:

1. Tracing and measuring learning trajectories in everyday life: a longitudinal understanding of cross-contextual, informal, and unintentional learning.
2. How can we build interfaces to externalize models/thinking, including of benefit to yourself, to get the effect of UI where people benefit from reflection, get it out of their own heads, personalize, and in a way that promotes collaboration?
3. A more complete picture of context: follow up search trails across different silos, study what happens offline, filling gaps between online accesses.
4. Search within an automotive context: use cameras, multisensors to provide context.
5. Contextual mobile search: use sensors to determine when and how to search.

Challenges

1. How can we get at contextual gaps that we can't currently observe?
   a. Resources include: ethnographers, log analysis, hardware/Kinect/sensor engineering, HoloLens, motion sensors, full body sensor, Amazon Echo, observing and capturing the work of experts.
   b. Use existing tools to look at awkward and/or more detailed data.
2. How can algorithms know what signals matter in context?
3. How can we tease apart multiple contexts that happen over time?
4. Does generating context help with reflection, meta-cognition, and learning?
5. How can we identify and exploit incidental learning opportunities in context?
6. How does context interact with learning? How can we measure learning in all of these different contexts?
7. How can we organize the context types we have, and how can we understand cost-benefit tradeoffs, and determine which features are most important (to measure, to infer, or to ask people about)?
8. How can we deal with context latency, where it takes time to process key features of a context, which may then become "stale" or less relevant?
9. How can we exploit context without it exploiting us: privacy issues?

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4.4 How can constructs and results from cognitive psychology and education be used to inform models of learning, knowledge acquisition, or mental representation during search interaction?

Participants: Gwen Frishkoff, Tim Gollub, Andreas Nürnberger, Yvonne Kammerer, Leif Azzopardi, Jiyin He, Rob Capra, Noriko Kando, Preben Hansen.

Introduction

The breakout group started with a general introduction and discussion of some of the general and basic models and frameworks used in cognitive psychology, education and IR. Especially, classical algorithmic IR and the interactive IR model, such as the Marcia Bates berry-picking model, Carol Kuhlthaus' ISP model and Dervin's sense making models, but also Pirolli's Information Foraging Theory [4] were discussed.

In interactive IR an episode could range from seconds in duration, to days or weeks, depending on the domain (for example, within the patent domain).. When working in the area of neuro-cognition, an episode usually lasts a second or less. The fMRI, EEG and ERP techniques were discussed and suggestions how they could be used were proposed. Temporal patterns and semantic priming can then be detected. The group also discussed the differences between performing laboratory tests and studies in natural setting and real-time.

For example, on the question if you want to measure if a person has understood something in a learning situation, do you need to do some prior measures? The answer to this question, suggested that a path to take could be to use measures of semantic priming. Another example is if a person is searching for a certain concept and then find it, this activity could be measured with biomarker comprehension. There is no cognition without motivation and emotion is part of the cognition. Domain general processes are learning and mental processes, while domain specific processes are processing things like sound and images.

From the cognitive psychology IS/IR area we can use several benefits of implicit methods, such as EEG/eye tracking (i.e. measures that do not rely on explicit responses to questions about learning, search outcomes). Vocabulary learning from multiple contexts illustrates incremental learning of information over multiple, diverse instances. The amount of information that the mind/brain is processing at any one time is large and mostly implicit (unconscious). Only a small fraction reaches consciousness, and conscious reflections on learning may or may not be correct. However, from a cognitive psychology point of view, the traditional search task descriptions are too complex and difficult to utilize.

Challenges

1. Dealing with information searching as learning, how studies and different data collection methods could be operationalized when an episode of a study could be a second or lesser?
2. Information Seeking and Information Retrieval use and apply many different kinds of methods. What can we use from cognitive psychology to correlate these methods? There are however, several challenges in using implicit measures: need for validation, cross-validation methods.
3. A third challenge mentioned is how to use ERP in a natural setting.
4. What if we could instrument every single second during a research study. How could it be utilized within the research of interactive IR? For example, if it is important to see a person spending effort in a certain learning situation and we want to measure it. One example discussed was to measure frustration.
5. How can different biomarkers be used? Temporal and stable markers is also something that can be measured and used to decompose obtained patterns.

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4.5 What type of functionalities and interventions on the search system interface level and the search algorithm level can foster learning?

Participants: Dan Russell, Preben Hansen, Michael Twidale, Gabriele Irle, Tim Gollub, Rob Capra, Soo Young Rieh, Grace Hui Yang, Dirk Ahlers, Yvonne Kammerer, Marcus Specht, Christa Womser-Hacker, Kevyn Collins-Thompson.

Introduction

This discussion focused not only on specific user interface affordances that could help learning, but also on issues and design principles that are important to keep in mind when creating such affordances for learning during search.

Issues

The goals and effects of user interface additions. We began this discussion with one participant describing a commercial search engine company's experiment to study the effect of new additions to the user interface. For example, some tooltips helped with advanced query operators, but some made things worse, because people would misinterpret instructions. So any interface design must be done with sensitivity that users are very different than search developers: we need much more information about a user. In general, a lot of search functionality is developed that doesn't invest time in this – new features are just deployed to test online, at scale. Other examples of consequences associated with new interface additions included dialog systems, in which user perceptions are very sensitive to timing – in general, sociolinguistic behavior and cues need to be considered as part of how users will interpret information. The use of benevolent deception [2] was also discussed, including the use of models that are simple but not necessarily accurate (as one related example: query autocompletion models can be heavily edited for simplicity/popularity, with the major effect of that feature to speed up query creation, not necessarily to provide the best alternatives for that user and query).

Interface elements that foster learning. Google Squared [1] was mentioned as an exploratory tool that would allow a user to find different common aspects of a class of objects, e.g. mammals, by adding a column to those from an existing set of Google Squared results. This is similar to the ability to find analogies between items: one could explore the conceptual space. Dialog-based systems have potential to help learning: recall that librarians used to ask followup questions. One advantage of agent-based systems is that they can get more context e.g. also through followup questions that go beyond the topic, or even the prosody of the conversation. Finally, allowing users to specify how they want to make tradeoffs might help them learn implicitly about the structure of a topic space (e.g. a taxonomy of objects) without explicitly showing them directly (leading to better retention). One example was mentioned from the Kayak travel website, which let users set sliders to specify tradeoffs instead of having to issue iterated queries – such features could give users a sense of sensitivity and immediate feedback, to understand how much narrowing down they need to do in a topic area.

How should new interfaces or algorithms be optimizing for better learning? As a counterpoint to "smart" search algorithms, the group discussed the idea that users sometimes just want to know what button to press – i.e. they just want an efficient, predictable tool. For learning, there is also a need to slow down, and be less efficient: time spent searching may be an investment in the future, and there may not be an immediate reward. Users may not always act with rational economic behavior, however. The use of conversational models has promise, but perhaps one goal should be to help students know what they don't know. Another goal could be to encourage broadening or lateral moves when exploring a topic: from a learning perspective, we often need a diversity of sources. This led to the question: what kinds of diversity are important for learning? In another direction, visualization approaches could also help users discover and explore, e.g. "Metro"-style maps of information [3].

Ideas for interface functionality

During the session, participants mentioned a number of ideas – from broad to very specific – of interface affordances or system functionality that could help with learning, or with developing learning-based systems.

1. Show a "controversy level" for search results, or flag when sources of points of view are not diverse enough.
2. Along the lines of search as a service (in particular, a dialog-based service): create a "search for learning" service to be shared. This could be an asynchronous service, so that search could deliver results over time in the background.
3. Patent search: add count info to query results to suggest where a patent examiner should focus.
4. Make it easier for humans to recall items and commands by providing cues (e.g. change in visual appearance).
5. Add adjunct elements to default search, e.g. through the addition of a sidebar. Users would start a search on their own but access the sidebar when stuck. For this, you would need to build in any new functionality during the transition period where a user learns to trust the new thing learns to use it effectively. This "persuasion" or "mentoring" itself would require new interface features. Users need to be able to control when they can invoke the new learning widget vs. resuming regular search.
6. Encourage users to type longer queries by using nudging behavior, e.g. a halo around text that would change color as users type.
7. Use taxonomies as a scaffold for certain kinds of learning tasks – perhaps via elastic lists.

Challenges and Opportunities

1. Increase dialog, followup questions, and more generally, the ability of a search system to engage in conversational agent behavior. More generally, we need a "context creation engine".
2. How can we track what users do with the information *after* the search to make sense of the information, and recognize the value of the search system?
3. How can we define diversity (in the search result sense) along different dimensions (topic, opinion, etc) and which types of diversity are appropriate for a given learning task?
4. What hints can we give users about search results and search process toward benefits for learning (e.g. diversity, serendipity, discovery, other users trails)?
5. Better exposure of the dimensionality of the retrieval space for user navigation.
6. When and how to target user learning during search tasks, or incentivize users to switch to learning – how could a system know what point in a task a student is at (e.g. a scientific process)?
7. How can search engine interfaces encourage self-reflection or comparison to other users (for calibration, motivation)?
8. What higher-level types of learning (e.g. finding analogies) could be supported by slower and/or human-in-the-loop processes?
9. Develop adjunct services that support learning and reflection, in addition to commercial search (and have components talk with each other).

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4.6 What are effective and scalable proxy signals for learning during search and search-related activities, and how can we measure and apply them?

Participants: Rob Capra, Yiqun Liu, Christa Womser-Hacker, Tim Gollub, Grace Hui Yang, Yvonne Kammerer, Andreas Nürnberger, Dirk Ahlers, Ujwal Gadiraju, Noriko Kando, Kevyn Collins-Thompson.

Introduction

In many cases, learning itself may be difficult, expensive, or invasive to measure directly. Proxy measures that are associated with learning (or lack of learning) can provide valuable indirect signals to information systems [2]. The discussion revolved around particular challenges to be solved, as well as ideas where there are opportunities for further progress.

Challenges

1. Which proxies to use and rely on will depend on the particular search task, so characterizing that interaction is an important goal.

2. How can we derive learning traces from a user's search trail? What are the relations we can get from such interaction sequences?
3. How can we study and support time-consuming queries that involve multiple steps or subtasks over extended periods: needs related to learning important facts or skills for life, financial management, job growth. This is hard to do in a lab study, where typically we give subjects the tasks, for a short period of observation.
4. How can we identify groups of people with similar learning needs in the same domain?
5. How can we detect what users need when learning: there are ultra-high priority learning needs: medical life-or-death search vs leisure learning.
6. How could we define a new learning channel where kids know they can go to (and which could be a source of new instrumentation)?
7. How could we use patterns of progression of query terms to gauge change in expertise over time, from progression of difficulty over time?
8. Most search models assume a cost-effective goal. What are other objective functions – and how can a search engine switch between these needs? E.g. hobbies, distraction. Should users tell the search engine directly? How should search engines account for e.g. a user's hierarchy of needs.
9. Can we measure user happiness as part of the user engagement scale?
10. Individual differences and personality need to be accounted for, but more work is needed on how to detect and support this. How inquisitive are you? How much do you need to understand?
11. There are three difficult prediction problems that should be distinguished. Can we know (1) *what* users learned vs. (2) *when* it happened vs. (3) whether they did learn *anything*? What classes of learning moments could be detected? For example, building on work by Yang et al. [5] can we identify learners' Eureka moments, from log and/or content features? Can we make use of additional signals from new sources, e.g. Kinect, skin conductivity.
12. How can we establish correlations between learning proxies and outcome measures, so that we can eventually reduce our reliance on more expensive/invasive proxies?

Opportunities

1. Rich content representations can lead to a host of new proxy features (e.g. work on reading difficulty and search [1]).
2. We could combine cognitive load and user navigational traces to identify learning goals. A certain amount of desirable difficulty may help indicate learning, or at least a context that is supportive of learning.
3. How can we think more broadly about educational applications, not just Web search. For example, the role of video (YouTube) as one of the main ways children learn can't be overstated at present, and that's underexplored.
4. Writing is a promising source of evidence of learning. At a high level, we can look at the semantics of the base content. Could we evaluate the quality of a summary according to how well it teaches a concept to someone else (or to a computer)? At a low low-level there's a lot of potential information in keystrokes and timing, e.g. what gets deleted and replaced.
5. Memory-retention/re-finding behavior could be a useful proxy, especially if we measure the difficulty of the concept being searched and re-searched – is it re-found more?
6. There are further opportunities for eyetracking : the video in mobile devices isn't precise, but we don't necessarily need high resolution for some important scenarios. For example,

we can detect reading or scanning by looking at e.g. back traces. We may also be able to discriminate between younger vs. older users, which could help disambiguate user characteristics [4].

7. Collaboration is still an area with many opportunities to understand and support learning: searching in a team, technology scouting, patent searching. How can we exchange learning results when there is an explicit learning trace? This could be applied in class settings: students could exchange traces [3]. Early work on collaborative IR captured some of this.
8. Studies of learning during test-taking, where the student is in a time-limited situation with access to online resources, could be a fruitful scenario to explore.
9. Most searches are not for learning. Are there learning-related verticals we could identify? Perhaps comparison shopping? Medical queries are one form of search where a user may be trying to learn something quickly.
10. There are further avenues for rich representations of users and tasks that exploit use of physiological signals: eye-tracking, skin, motion and video, audio.
11. There are likely to be further gains from work processing implicit signals: mining data from search trails, log features, queries and content, as well as explicit signals: mine data from e.g. collaborative communication.
12. Establish a learning-dedicated search "channel" that builds on existing commercial search as a service.
13. Establish correlations between proxy measures, outcome variables.

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4.7 How can learning performance and learning outcomes be measured during search? What search process features can act as indicators of learning?

Participants: Heather O'Brien, Ran Yu, Andreas Nürnberger, Noriko Kando, Yiqun Liu, Gwen Frishkoff, Ujwal Gadiraju, Leif Azzopardi, Jiyin He, Claudia Hauff.

Introduction

One of the most often recurring issues during the seminar was the issue of measuring learning gains that have occurred during search episodes. The standard approach of a pre-test → search episode(s) → post-test to measure these learning gains is not scalable, time-intensive to set up and only viable in a laboratory study. These inherent bottlenecks have led researchers to consider proxy measures (e.g. the change in vocabulary use during searches, the application of knowledge in downstream tasks) that are easier to collect at scale. A large part of the discussion revolved around scalability, different types of proxies and the ability to generalize beyond specific tasks and contexts.

Open questions

1. What scalable measures, based on search behaviours and document characteristics are good approximators of learning gains (and when is "good" good enough)? To what extent are measures task- and domain-specific? Across which periods of time (if we think for instance about sequences of queries across sessions) can we reliably measure learning gains?
2. Should the emphasis be on measuring learning, given all of the potential confounds? Or should we be looking at capacity to learn in the search process? There is also the role of probes in the search experience to test understanding as people make progress (challenge: level of intrusiveness).
3. Can we measure learning gains in downstream tasks, for instance by connecting users' search logs with their GitHub traces and observing the coevolution of both along several dimensions?
4. Laboratory studies have often elaborate setups to measure learning gains. At the same time though, they tend to measure learning on a very small number of topics or via a specifically-designed search tool. To what extent can we generalize the results of these small-scale studies to other domains and tasks?
5. Is it possible to measure the quality of a learning path towards the formal learning of a particular skill by taking advantage of textbooks' structures as ground truth?
6. Retrieval practice (the repeated testing of knowledge) has been shown to be beneficial to learners. Can we integrate a retrieval practice component into the search process, given that today (at least Web) search has been designed to minimize the amount of duplicate information? An added benefit of such a component: the retrieval practice questions can act as probes to test understanding and learning progress.
7. Learning through failure: users may also learn when their information needs are not satisfied and their goals are not achieved. How can we deal with that?

4.8 How should we address the conflict between the need/expectation of fast search and the need for more time in learning?

Participants: Michael Twidale, Ran Yu, Gabriele Irle, Soo Young Rieh, Heather O'Brien and Preben Hansen.

Introduction

A search engine is a quick way to get information and followed by reflection. Sometimes you also get results that require you to slow down in both the learning and searching process. It may be necessary that you look into the search result after the search. In this way the search actually continues. Therefore, the post-search activities are important. When people create something after a search activity, the search is a more engaged activity and thus, the search process is a sub-process in the learning process.In learning processes, the search activity is considered to be an instrumental activity unless the learning task is about learning how to search.

Search results. The search results should include alternative ideas that could be of interest to a person's search goal. Content-related focus in search results. Designing the "nudge" in the search activity.

Creativity. Creativity has been the focus for a long time in other disciplines such as HCI, Interaction Design and Industrial Design. These research fields have developed creativity principles, such as IDEO. Creativity and ideas may have certain characteristics, such as that ideas percolate and that creativity emerges through composition.

Creativity as part of the search process. Examples for enable randomized creative processes are, for example, IDEO's card deck and Brian Eno's (see below) creative strategies for music.

Challenges

1. Creativity and search. How we can deploy creativity (Keith Sawyer, 2013) during the search process and how to deploy creativity in our search activity.
2. To be able to design search systems so that they have different "Moods". The user could choose from these moods. How about slowing down the search system and at the same time speeding up the learning process? Design a system so that functionalities adapt to the learning process. Another dimension could be to design systems so that they show breadth and depth.
3. Playfulness in search systems. Purposeful and serendipity approaches in search systems. For example, a bookstore and a newspaper can be a metaphor for involving learning. Building a representation of a process people have been involved in.
4. How about to suggest some functionalities that perform slightly less accurate, fast, on-topic, relevance that may result in reflection.
5. Creativity in the search process. Designing for creative methods for searching as well as for search for creativity.
6. Experiment challenge: Bring two different papers from two different areas. Creative search. Predict what can emerge from merging these two.

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4.9 How can search systems become more conversational to include or promote learning?

Participants: Alyssa Wise, Jiyin He, Rebecca Reynolds, Dan Russell, Marcus Specht, Leif Azzopardi, Claudia Hauff.

Introduction

Commercial Web search engines are not built to support users in the type of complex searches often required in learning situations. Finding, understanding, analyzing and evaluating the documents containing information relevant to answering a complex question is a time-consuming and cognitively demanding process which requires an interactive dialogue between the search system and the user. A good conversational agent would act similar to a librarian reference interviewer who clarifies ambiguous statements, understands the context of the search and fixes category errors. Although this is currently beyond our technological abilities, in this breakout group we discussed the implications of such a conversational search approach.

Open issues

1. How should a conversational agent (presumably trained automatically on vast quantities of text) deal with questions to which no clear consensus answer exist ("Does God exist")?
2. How much of a dialogue are users willing to engage in?
3. Does the dialogue have to be explicit or can we make use of user signals that implicitly provide a dialogue response?
4. Collaborative search (several users searching together) could also be conducted with one user and several agents; how would such collaboration look like?
5. What are the functions and objectives of a conversational agent? How should a conversational agent behave when learning is the user's objective (e.g. engage the learner to not give up)? How important is the social aspect of a conversational agent?
6. Can a conversational agent act as a simulated learner to facilitate engagement with the content and help the user to clarify information? How can we design a system that incorporates deep models of learning?
7. Can we emulate how intelligent tutoring systems guide their users through the learning material? Can conversational agents guide users through those parts of the search space they have not considered before? If we do so, does that lead to more collective agreement on contentious issues in parts of the society (e.g. climate change)?

5 Panel discussions

5.1 Closing Panel Session

Claudia Hauff (TU Delft, NL), Robert Capra (University of North Carolina – Chapel Hill, US), Kevyn Collins-Thompson (University of Michigan – Ann Arbor, US), Gwen Frishkoff (University of Oregon, US), Preben Hansen (Stockholm University, SE), Noriko Kando (National Institute of Informatics – Tokyo, JP), Soo Young Rieh (University of Michigan – Ann Arbor, US), Daniel Russell (Google Inc. – Mountain View, US), and Christa Womser-Hacker (Universität Hildesheim, DE)

The closing panel discussion featured provocative questions from the participants followed by answers from the panel. We present the panel discussion as follows. First, the question raised by a person in the audience is reported, followed by different answers from the people in the panel. The panel was followed by a wrap-up session in which all participants discussed opportunities for community-building and resource sharing, proposal funding, and future collaboration.

Panel Session

The panel consisted of the following participants: Soo Young Rieh, Christa Womser-Hacker, Dan Russell, Noriko Kando, Gwen Frishkoff, Robert Capra.

Q: Where is the real impact of this research line? Is it just an academic exercise? Why now?

1. What is the impact of information on people? We have done basic Web search, we need to take the next step.
2. People have become comfortable with searching. There is a need for more sophisticated tools. Google is not designed as a learning system and yet people use it for learning. This is a high-value very specialized vertical. In this area it is really easy to try something and it fails spectacularly (e.g. Google Notebook). It is easy to build something super cool, however, it needs to be "dead simple" to be adopted. As an outsiders to the commercial search engines we need to build associative/auxiliary systems.
3. There are options for this type of research (outside of the 'Google sphere'). There are currently many 'if's' in the IS/IR research discussions. We should think about how to make them smaller.
4. We should not forget the notion of 'search as learning' as 'learning to search'!
5. Discussions focus still on the individual level; we should also consider the group level; search needs to become a societal research agenda.
6. We need a context generator ("total perspective vortex"). Social search/learning is not an echo chamber, it is a prison cell.

Q: How might we use the analogy of librarians and librarianship to be inspired for search as learning?

1. Study shows that 55% of answers by librarians are correct; but is this really the gold measure? Instead of measuring accuracy we should measure how often people come back to learn more (teaching moment)
2. Conversational agents have made it into Google, it is not a reference librarian (yet) but it can move into this direction

Q: How do you see the role of the scientific community?

1. Don't focus on things Google or Bing are good at (computations, algorithms, coding); Google isn't doing a lot of things with children search, neuro-measures, etc.

Q: What happens in the future?

1. I can ask meaningful deep questions and get synthesized complete answers.
2. Eco chamber phenomena mix learning with opinions.
3. In the future people will go back to and remise about the times without so much technology
4. Technology will be more friendly to every type of user
5. We will engage/interact with search in richer ways; richer interfaces
6. Smarter technology vs. making people get smarter; we should not get lazy
7. Ontologies are the backbone of knowledge

Position: The real essential breakthroughs will come from sensors and signal processing + AI/DNN, not better educational models or even retrieval algorithms.

1. Don't agree, we need better metadata!
2. But sensors can provide metadata!
3. Data is not the problem, making sense of it is, we need underlying models
4. Discussion on sensecam-like technologies
5. I want to search my "brain", I want to make the internal knowledge structures explicit to others e.g. in teaching

Wrap-up session

The purpose of the wrap-up session that took place as the final session was to look forward and discuss how we could take this further and how we may collaborate. This included examples of potential funding sources, additional publishing venues, datasets and evaluation frameworks, and community outreach ideas. The present Dagstuhl seminar also connects to goals and ideas described in the SWIRL report (Allen, 2012).

1. Biased structuring of search results. Think about SIGCHI, connections to interactive sense-making.
2. Some interesting resources for further connections:
   a. ASIST special interest group.
   b. PSLC DataShop learning data (https://pslcdatashop.web.cmu.edu/).
   c. ISLS: International Society of Learning Sciences (https://www.isls.org/) .
   d. CSCL (Computer-Supported Collaborative Learning).
3. A special issue on SAL for JLA (Journal of Learning Analytics) is possible.
4. Work on an idea for a Morgan & Claypool monograph.
5. A special issue on Searching as Learning was issued 2016 Journal of Information Science, Volume 42, Issue 1, February 2016
6. Funding:
   a. FET supported action: 150k to support coordination/exchange across countries, or even toward supporting a center. (NSF may have something similar reciprocal.)

b. Horizon 2020 giant funding grant scheme (January learning-related. 120 pages). 5% success rate.
c. COST: European proposal (travel funding). Innovation Training Network: partners with other countries. Existing COST KEYSTONE: Researchers from the area of database and information retrieval.
d. NSF Building Community and Capacity: data-intensive research in education, workshops.

7. University of British Columbia and Peter Wall institute offer funds for international workshops (25K).
8. There is also a need for a common dataset, evaluation framework to compare, design specific tasks, and define experimental methodology. Could make a workshop to analyze shared dataset. Make annotated data available (with inconsistencies).
9. Propose/run a TREC shared task on search as learning. For inspiration, see MMM competition: video browser showdown, or demo showdown. This could also be possible at CLEF since they has a more exploratory mode (multilingual).
10. Tutorials at SIGIR and related conferences on this area can help encourage submission of further papers in SAL.
11. Short-term exchange student research visits between universities.
12. Propose further SAL-related workshops at upcoming conferences.
13. Other communities for outreach: core education at classroom, cognitive modeling, social media, computational social science, communications, machine learning expert.

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