Measuring Exploration/Exploitation Decisions in (Un)/Expected Uncertainty-driven Web Search

Thomas WIEBRINGHAUS

ifes – Institut für Empirie & Statistik, FOM University of Applied Sciences
Herkulesstr. 32, D-45127 Essen

Abstract: Many of our decision-making processes are performed unconsciously. Our cognitive decisions are adapted and optimized by evolution to a constantly changing and unknown information environment. Human beings balance the decision when to explore new information (or to reduce the uncertainty) and when to switch to exploit the current information or options. In this ongoing project it is hypothesized that this explore/ exploit balance changes once the subjective aspiration level is exceeded. The optimal trade-off to explore new information or to exploit the available resources for collecting information is under current investigation in Information Foraging Theory (e.g. improving search engines) and Reinforcement Learning Theory (e.g. motion planning for robots). Method evaluation and first results are presented and discussed.

Keywords: explore/ exploit trade-off, expected uncertainty, web search behavior

1. Introduction and Aim

1.1 Information Foraging Theory and the Explore/ Exploit Dilemma

In Information Foraging Theory (IFT), the information seeking user behavior is described as a forager exploring his hunting ground or territory for new food or exploiting and depleting a found food patch (Stephens & Krebs 1986; Pirolli & Card 1999). When regarding a web search, human beings explore new information by using a search engine or exploit a web resource to consume the found information. Seeking new information or knowledge in web searches is similar to gather or exploit food patches in an uncertain world. The optimal search policy in this explore/ exploit trade-off may vary depending on the goal and the user (Cohen et al. 2007; Hills et al. 2015). Moreover, human's rationality is bounded by restricted cognitive capacity, limited time and information status of the unknown and uncertain environment. Although a simple information retrieval is performed within a few minutes, aspiration levels are adapted when search time exceeds the anticipated information gain, called satisficing (Simon 1955, Prabha et al. 2007). Human cognition developed strategies to cope with this complexity with near-optimal solutions (Sang et al. 2011 & 2018). Deciphering the cognitive balancing and satisficing is currently a main topic not only in behavioral psychology (Agosto 2002), but also in decision theory and reinforcement learning theory (Börgers & Sarin 2000; Kohno & Takahashi 2017).

1.2 Aim of Study

This ongoing project aims to develop an observational study where participants execute a web search under natural but experimental conditions to examine a putative alteration of web search behavior when exceeding the individual aspiration level. Moreover, a potential web search adaptation by the transition of expected to unexpected uncertainty is hypothesized here. It is assumed here that users expect finding the information within self-estimated processing time, whereas the experience of not solving the task within expectation time is unexpected, and hence information seeking behavior might change.

2. Method Development and First Results

2.1 Development of Search Task

To examine the explore/ exploit behavior properly, it is important to find a task that ensures a prolonged web search in *one* single task for >10 minutes.

Several web search tasks with varying difficulty and demands were scrutinized to ensure extensive observations during one prolonged single search. The calibration studies revealed that an extended web search is obtained when the task appears very simple, but finding the solution is more time-demanding than assumed. As the average web user is not familiar with sophisticated information retrieval techniques, it is practical to combine demands that are usually solved by applying Boolean operators. As the common web search engines do not include e.g. a range of numbers or involve all synonyms, it is helpful to exclude the typical standard naming in the search task.

Pre-studies were accomplished and an enhanced and motivated search was repeatedly observed for >80% of participants for > 15 minutes with the task: *"Please search the most expensive chocolate under fair-trade conditions having > 80% cacao from a well-known offline discounter".* Note that finding a price in a discounter appears simple but e.g. typical shopping meta-search engines do not cover a restriction to fair-trade products or to discounters (which is not identical to classical supermarkets), most information is found about online prices, the restriction to more than 80% cacao needs different inputs (e.g. 81%, 82%, etc.) and *most expensive* indicates a comprehensive comparison of all suitable products and thus the point of task completion is not obvious.

The individual aspiration level is difficult to find directly and may vary. As a first attempt, participants may estimate the processing time. This estimation is assumed to be aligned to the aspiration level. Potential alterations of web search behavior close to the individual estimation point should be examined.

2.2 First Results

Initially, n=23 students participated on the calibration study. However, 12 (52.2%) data sets were omitted because participants experienced internet difficulties (n=7), quit web search after encountering a matching result after ~ 2.5 min. (n=2), used an internet browser not tracking visited links (n=2) or did not complete the survey (n=1). The remaining 11 valid data sets were analyzed (mean age = 22.18; sd = 0.94; four female).

Each participant operates under the same conditions in the same information environment. Processing time was estimated on average with 5.6 minutes (table 1). First results encompass duration of 15 minutes search time and are shown in table 1.

Table 1: *time_est = estimated processing time, adapt = number of new queries in search engine, explore = total number of visits of search engine (including new queries), exploit = number of clicks on links, exp-adapt = exploration – adaptation (number of clicks on search engine result page (SERP), rel_adapt = relative adaptation, rel_explore = relative exploration, rel_exploit = relative exploitation, sd = standard deviation, CV = coefficient of variation*

	time_est	adapt	explore	exp-adap	exploit	sum	rel_adapt	rel_explore	rel_exploit
mean	5.55	9.64	16.18	6.55	16.00	32.18	0.30	0.50	0.50
median	5	10	19	5	16	32	0.26	0.52	0.48
sd	2.18	3.34	5.34	4.66	5.97	7.88	0.09	0.13	0.13
CV	0.39	0.35	0.33	0.71	0.37	0.24	0.29	0.27	0.27

The range of the relative exploration time was 0.23 to 0.74 (mean = 0.50; median = 0.52 and sd = 0.13). Omitting the maximum and minimum value, the resulting 9 observations (81.81%) are close to ~50% (~40 to ~60% or 50%+/- 10%). On average, participants balance exploration and exploitation time to ~50%.

3. Conclusion and Outlook

Calibrating experimental conditions with a qualified task results in an estimation time of 5.6 minutes on average, denoting an envisaged misestimating of search time and an underrating of task complexity. The observations of a small calibration group suggest that web searchers balance the explore/ exploit decision unconsciously to ~50% when seeking information.

As a measure for the internal aspiration level for satisficing, the processing estimates are further regarded as an initial reference point. Ongoing studies will examine if search behavior changes close to the point of satisficing. More insight into satisficing will contribute to a deeper understanding of cognitive strategies and observations might inspire new optimization algorithms in artificial intelligence, e.g. reinforcement learning.

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