Human Strategic Balancing or Random Sampling in Exploration and Exploitation Decisions under Continuous Uncertainty in Web Search Interaction

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Background and Aim: One of the most time-consuming tasks for human beings is seeking information to reduce uncertainty. Some web interactions resemble a simple sequence of consecutive queries, others constitute an evolving reciprocal exchange between an exploratory step seeking unknown information, followed by an exploitative phase of already known parts of the environment. Recently, it was observed that participants performing a tailored open-ended web search task that maintains the user under continuous uncertainty, showed a balanced ~50% exploration/exploitation ratio (Wiebringhaus 2019). However, as a decision to ~50% is phenomenologically equivalent to a random search (Schulz and Gershman 2019), the underlying generative process is unknown. Understanding the cognitive “algorithms” e.g. of the explore-exploit dilemma is an active area of research (Osugi et al. 2005; Cohen 2007; Settles 2009; Bocanet & Ponsiglione 2012; Reverdy et al. 2012; Bounéffouf et al. 2014; Wilson 2014). It is hypothesized here that the dispersion of data might give insight into the underlying structures that deviate from a pure random process.

Results: Outlier tests indicate the maximum exploration ratio as an outlier, which was not eliminated for further analyses. Five normality tests support normally distributed data for absolute explore and exploit decisions (data not shown), and for the exploration ratio: Figure 1 shows boxplots of absolute click decisions after 15 min, indicating a balanced exploration and exploitation.

![Boxplots of absolute clicks](https://example.com/boxplot.png)

**Figure 1:** Boxplots with absolute clicks (y-axis) for explore and exploit decisions (n=17).

Shapiro-Wilk Test (p=0.999), Anderson-Darling Test (p=0.972), Cramer-von Mises Test (p=0.969), Pearson chi-square Test (p=0.671) and Shapiro-Francia Test (p=0.963).

Table 1 shows descriptive statistics of the exploration ratio with mean and median close to 50%. One-sample t-test shows no significant deviation (p=0.294) from a uniform equal ratio of 0.5 for the exploration ratio. The kurtosis is close to a standard normal distribution and slightly platykurtic. The distribution is positively skewed. A significant Pearson correlation between exploration and exploitation decisions suggests a linear correlation between the two variables (Pearson 0.519; p= 0.033). Figure 2 demonstrates a kernel density estimation for both absolute decisions compared to a uniform random distribution on the observed interval [5,34].

![Kernel density estimation](https://example.com/kde.png)

**Figure 2:** Kernel density estimation of absolute explore and exploit (blue), compared to a uniform random distribution on the observed interval [5,34]. Density: y-axis.

Conclusions: Empirical evidence is presented that a web search exhibits a 50/50 balancing of explore/ exploit decisions when performing a web search under continuous epistemic uncertainty. Hofmann (2011) also demonstrated that balancing exploration and exploitation can “significantly and substantially improve cumulative performance”. It is suggested here that human agents sequentially change and balance both activities as a reinforcing tradeoff to benefit from not exploring or exploiting too much to the exclusion of the other, following the opinion by Chen & Katila (2008). Without an information scent, the principle of insufficient reason might be the optimal information seeking mode under uncertainty. Further analyses might focus on ratio distributions which are often heavy-tailed and exhibit more interesting properties (Hayya 1975; Marsaglia 2006). Future studies will focus on Shannon entropy and Kullback Leibler Divergence to study information gain under continuous uncertainty. Furthermore, future research might benefit from cognitive search strategies, e.g. for Active Learning where agents proactively utilize training samples to find a compromise of the exploration-exploitation dilemma (Osugi et al. 2005; Settles 2009; Bounéffouf et al. 2014).

All references see:
Please cite as: Wiebringhaus, Thomas “Human Strategic Balancing or Random Sampling in Exploration and Exploitation Decisions under Continuous Uncertainty in Web Search Interaction” Gesellschaft für Arbeitswissenschaften (GfA) Conference Proceedings 8.17.7 Berlin, Germany, 2020

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