

Efficient Interaction through Information Maximization

Keywords: HCI, mutual information, interaction

Context of the project Designing user interfaces is an iterative process. A designer creates an initial version based on their intuition and experience, then tests it with users and refines it based on feedback. This cycle is repeated until the interface is considered satisfactory. While effective, this approach is often slow and resource-intensive, as it requires many rounds of trial and error between designers and users.

To address this, researchers have proposed computational methods that automatically generate or optimize interface designs [2]. These methods rely on defining an objective (or “cost function”) that captures what makes a good interface, and then optimizing the design accordingly. However, a major limitation is that such objectives must be carefully crafted for each specific problem, which can be difficult.

This thesis explores a different approach: instead of designing task-specific objectives, it investigates whether general principles from information theory, specifically measures of how much information is exchanged between user and system, can be used to guide interface design in a more universal way.

Goal of the thesis One promising idea in this direction is Bayesian Information Gain (BIG), introduced by Liu et al [1]. BIG is an interaction technique in which the system actively guides the user toward actions that are most informative (ie., actions that help the system quickly understand the user’s goal). Intuitively, the system tries to “ask the best possible question” at each step through its interface, so that the user’s response reveals as much useful information as possible.

Although promising, BIG has several limitations. It is computationally expensive, has mainly been tested in small and discrete settings, and requires a calibration phase before use, which limits its practicality and adaptability. It also does not account for important usability aspects, such as proximity (the interface should not change too abruptly between steps, to avoid disorienting users) and intrinsic state value (some interface states may be inherently preferable, regardless of how informative they are). More broadly, BIG is only one of several recent approaches that use information-theoretic measures to design interactions (see positioning section).

The first goal of this thesis is therefore to review and compare these different information-based approaches. This includes analyzing their theoretical properties, but also their practical characteristics, such as computational cost, ability to handle continuous or real-time interaction, and suitability for different application contexts. The second goal is to address the limitations of BIG. Since many of these approaches rely on similar mathematical concepts (notably mutual information), improvements developed for BIG are likely to extend to other methods as well. Key challenges include estimating information efficiently from limited user data, and incorporating usability constraints such as smooth transitions and meaningful interface states.

As part of this work, the candidate will develop a software library implementing both existing and newly proposed methods.

The third goal is to evaluate these approaches in realistic applications (map navigation, text entry etc.)

Positioning in relation to the state of the art Several computational approaches have been proposed to automatically design user interfaces, with applications such as menu organization, adapting interfaces to different devices, optimizing keyboard layouts, or improving visual aesthetics. These

methods typically rely on defining explicit objectives (e.g., speed, accuracy, visual appeal) and assigning weights to them. However, deciding what these objectives should be, and how important each one is, can be difficult and often depends on the specific application.

This thesis explores an alternative approach based on mutual information, a concept from information theory that measures how strongly two variables are related. Intuitively, it captures how much knowing one thing (e.g., a user’s action) tells us about another (e.g., their goal). Because it is generic and does not depend on a specific task, mutual information is a promising candidate for guiding interface design in a more universal way.

One of the first approaches in this direction is Bayesian Information Gain (BIG), proposed by Liu et al. BIG selects interface states so that the user’s next action reveals as much information as possible about their goal. In other words, it steers the interaction toward situations where the system can quickly “figure out” what the user wants. BIG has been successfully applied to navigation tasks, such as exploring maps or file systems, as well as information browsing.

Related ideas exist in other fields. For example, the concept of empowerment, introduced by Polani and colleagues [4], also relies on mutual information. It measures how much influence an agent has over its environment through its actions. Systems that maximize empowerment tend to favor states where the user has many meaningful options.

More recently, Reddy et al. proposed MIMI [3], that extends the notion on empowerment. MIMI maximizes the relationship between user commands and how the interface responds to them. This leads to co-adaptive interfaces, where both the user and the system gradually adjust to each other over time to improve interaction efficiency. MIMI has been evaluated in scenarios such as controlling a noisy computer mouse and simple interactive games.

Impact Mutual information is a problem-independent measure of the dependence of two random variables. As such, mutual information, and as a result, the output of this PhD should be applicable to a very wide range of problems in various contexts in HCI. The candidate is expected to produce a software library, which greatly increases the likelihood of a transfer (including to industry).

Implementation Methods The PhD student will:

Year 1–2 Review and compare the mentioned mutual information metrics on analytical and empirical grounds.

Year 2–3 Address BIG’s shortcomings and demonstrate on empirical grounds

Year 1–3 Develop and maintain a software library implementing algorithms needed for mutual information maximization and inference.

Supervision The PhD student will be mentored by Julien Gori, a young HCI researcher with expertise in information theory, and Olivier Rioul, a senior researcher in information theory and applied mathematics. The work will be published primarily in the top HCI forums (UIST, CHI, TOCHI), as well as in forums for applications of information theory.

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Candidate Profile The candidate will have an interest and demonstrated expertise in computational modeling. Interest and prior knowledge in experimental research and software programming, and knowledge of basic information theoretic notions will be appreciated. Please send a CV, M1/M2 transcripts with your application, and a copy of your master’s thesis.

References

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