# A Bayesian Experimental Design Approach Maximizing Information Gain for Human-Computer Interaction

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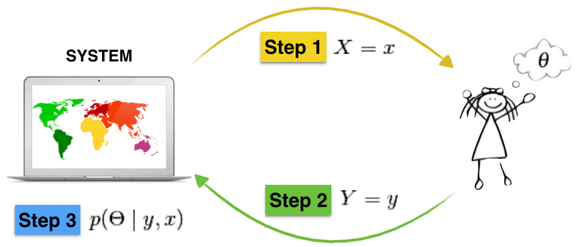
## Introduction

A new information-theoretic approach based on **Bayesian Experimental Design (BED)** is applied to human-computer interaction, and in particular to multi-scale navigation. Instead of simply executing user commands, our **BIG (Bayesian Information Gain)** technique is modeling user behavior and tries to gain information by maximizing the expected mutual information provided by the users' subsequent input.

## Notations

| | BED | BIG |
|---|---|---|
| $\theta$ | parameter to be determined | intended target in users' mind |
| $y$ | observation | user command |
| $x$ | experiment design | system feedback |
| $p(y\|\theta,x)$ | model for making observation $y$, given $\theta$ and $x$ | model for user providing command $y$, given $\theta$ and $x$ |
| $p(\theta)$ | prior | system's prior knowledge about users' goals |
| $p(\theta\|y,x)$ | posterior | updated knowledge |
| $I(\Theta;Y\|X=x)$ | utility of the design $x$ | utility of the feedback $x$ |
| $H(\Theta)-H(\Theta\|X=x,Y=y)$ | utility of the experiment outcome after observation $y$ with design $x$ | utility of the outcome after user input $y$ with system feedback $x$ |

## BIG Approach




**Init:** $p(\theta)$ ; $p(y|\theta,x)$

**Step 1** Find $x$ that maximizes:

$$I(\Theta;Y|X=x) = H(\Theta|X=x) - H(\Theta|Y,X=x)$$
$$= H(\Theta) - H(\Theta|Y,X=x)$$

**Step 2** Send $x$ to the user and get user command $y$.
The actual information gain is:

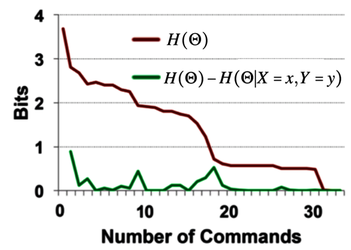
$$H(\Theta) - H(\Theta|X=x,Y=y)$$

**Step 3** Update the probability distribution and compute posterior $p(\theta|y,x)$ from prior $p(\theta)$.

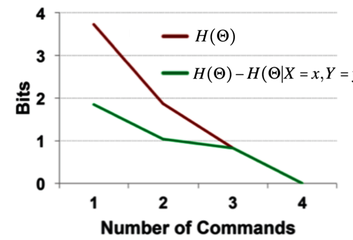
$$P(\Theta=\theta\,|\,X=x,Y=y) = \frac{P(Y=y\,|\,\Theta=\theta,X=x)P(\Theta=\theta)}{P(Y=y|X=x)}$$


## Controlled Experiment

A controlled experiment with 16 participants comparing **BIG** method and standard **Pan&Zoom** navigation.

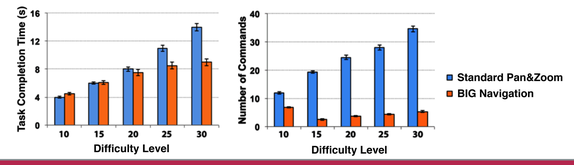



**Standard Pan&Zoom Navigation**




**BIG Navigation**

In BIG navigation, after each user command, the uncertainty the system has about users' goals decreases on average: $\mathbb{E}_{x,y}\big(H(\Theta|Y=y,X=x)\big) = H(\Theta|Y,X) \le H(\Theta)$




## BIGmap

Apply **BIG** to a more realistic map application where the probability of a city is proportional to its population

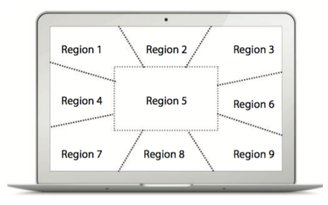

## Perspectives

The Bayesian Information Gain model opens up a wide range of opportunities for Human-Computer Partnership, which combines user control with machine power:

- $x$ any system feedback
- $y$ any user input
- $p(\theta)$ the system's prior knowledge about users' goals

Other applications: searching tasks such as file search.

## Application to Multi-scale Navigation


- $x$ a particular view the system sends to users
- $y$ user input discretized into 9 commands (8 pan directions and 1 zoom-in region)
- $p(\theta)$ the system's prior knowledge about the points of interest in users' mind
- $p(y|\theta,x)$ user behavior is modeled from a calibration session

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