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

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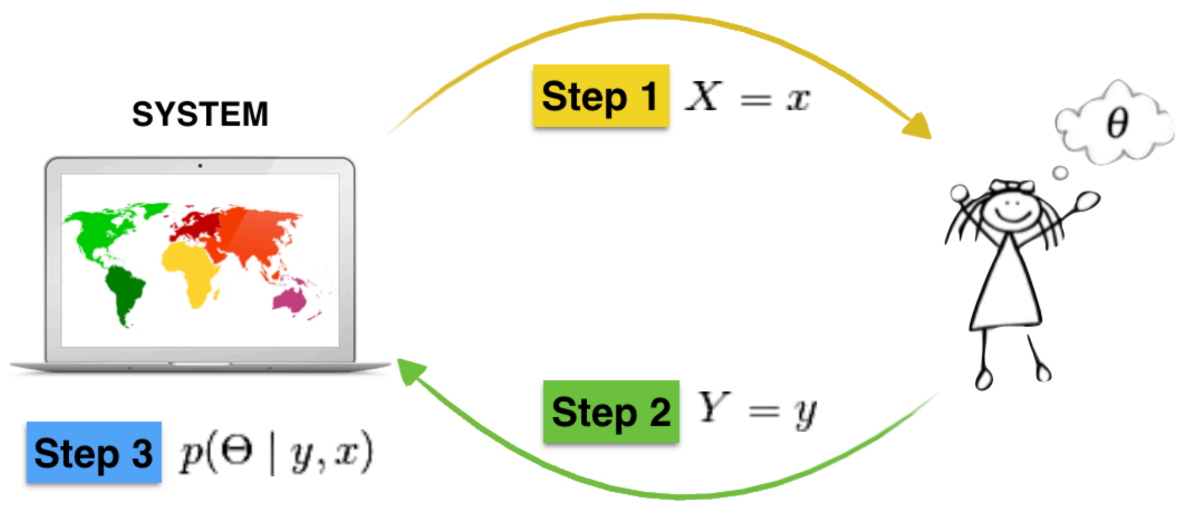
Introduction

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
θ	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 θ and x	model for user providing command y, given θ 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:

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

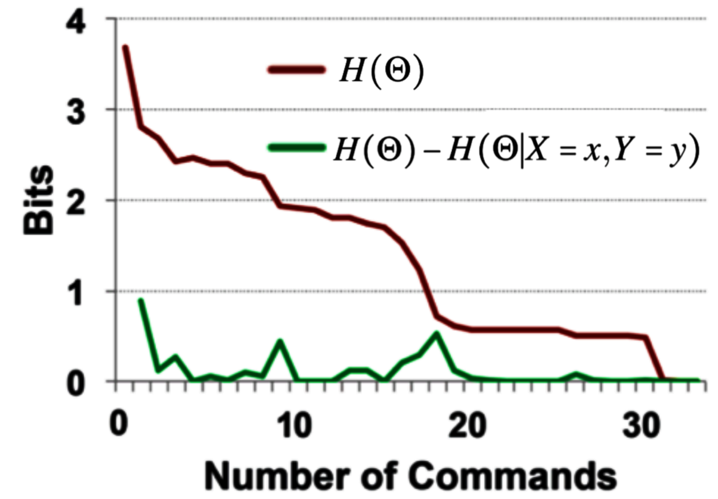
Yay! → **If Target Found** → End

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

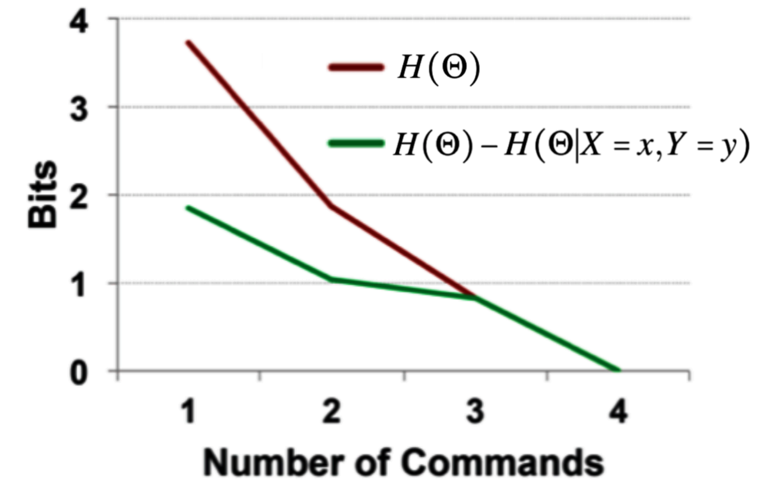
$$P(\Theta=\theta \mid X=x,Y=y) = \frac{P(Y=y \mid \Theta=\theta,X=x)P(\Theta=\theta)}{P(Y=y|X=x)}$$

Controlled Experiment

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

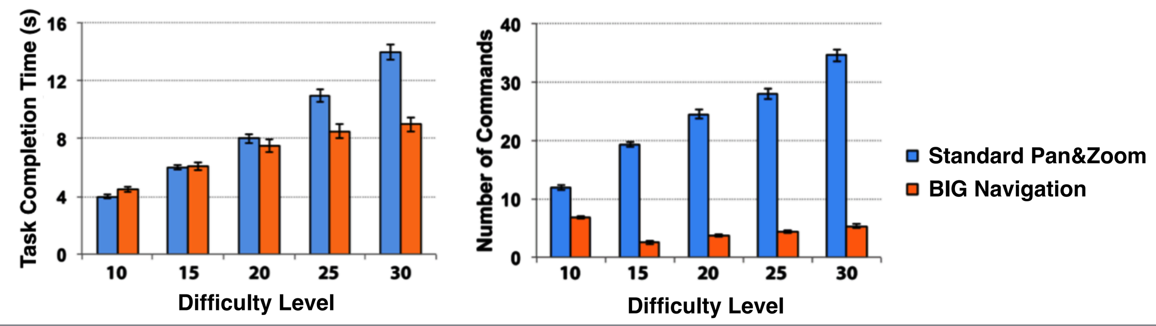


Standard Pan&Zoom Navigation



BIG Navigation

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



BIGmap

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

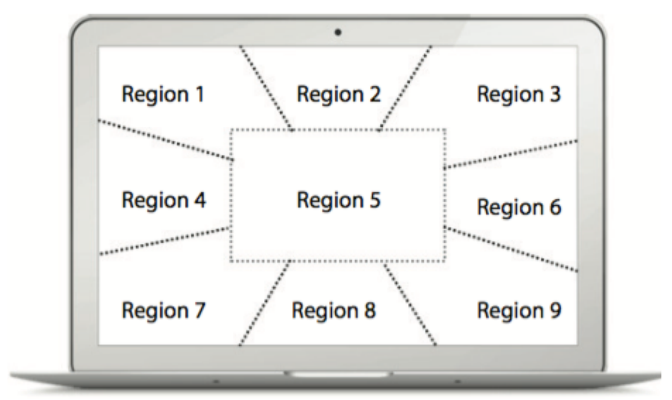
Perspectives

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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