Information Flow Experiments
Methodology
Personalized Web Advertising
Personalized Web Advertising

Confounding factors:
Other users
Advertisers
Websites

Web Browsing

Ad Ecosystem

Advertisements
Experimental Design

Confounding factors:
Environmental factors
Genetic differences

Drug → Biological System → Surviving Cancer
Experimental Design

Drug → Biological System → Surviving Cancer

Confounding factors

Different Outcome?
Information Flow Experiments

Web Browsing \(\rightarrow\) Ad Ecosystem \(\rightarrow\) Ads

Male \(\rightarrow\) Confounding factors \(\uparrow\) \(\rightarrow\) Female

Different Outcome?
## Information Flow Experiments as Science

<table>
<thead>
<tr>
<th>Experimental Science</th>
<th>Information Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural process</td>
<td>System in question</td>
</tr>
<tr>
<td>Population of units</td>
<td>Subset of interactions</td>
</tr>
<tr>
<td>Treatments</td>
<td>Inputs</td>
</tr>
<tr>
<td>Responses</td>
<td>Outputs</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Causation</td>
<td>Information flow</td>
</tr>
</tbody>
</table>
Noninterference

Program

High input

Female

Low input

Low output

Job ad

Same low output

Same Program

Different high input

Same low inputs

[Googuen and Meseguer, 1982]
Probabilistic Noninterference

- High input
- Female
- Low inputs

Program

Low output distribution

- Same low output distribution
- Same Program

Different high input
- Male

Same low inputs
We would like to test the following

• Null hypothesis
  – The outputs from the experimental and control units are drawn from the same distribution

• Apply a significance test
  – On the outputs from the two groups
  – Returns a p-value
  – Reject the null hypothesis if p-value < 0.05
Mechanism of ad delivery is complex
Browser agents may not be independent
Our Idea:

• Use a non-parametric test
  – Does not require a model for Google

• Specifically, a permutation test
  – Does not require independence among browser instances or assumption that ads are independent and identically distributed
Permutation Test [Good’05]

- It is a non-parametric test
  - No assumptions about ad distributions
- It does not require independent samples
  - Ads served to one browser can affect ads served to another
- Assumption: Samples are exchangeable under the null hypothesis
- A statistic that discriminates between the null and alternate hypotheses

Observations \((x_1, x_2, \ldots, x_n)\) are exchangeable if the probability of any particular joint outcome is the same regardless of the order.

P. Good.
Permutation Test: Example

![Graph showing car-related ads](image)
Permutation Test: Example

\[ s(\vec{y}) = 119 \]

\[ \vec{y} \text{ is the measurement vector} \]

\[ s(\vec{y}) \text{ is the statistic computed over } \vec{y} \]
Permutation Test: Example

\[ s(\pi(\vec{y})) = 67 \]

\[ \pi(\vec{y}) \] is a permutation of \( \vec{y} \)

\[ s(\vec{y}) \] is the statistic computed over \( \vec{y} \)
Permutation Test: Example

\[ p\text{-value} = \frac{\text{count}[s(\tilde{y}) \leq s(\pi(\tilde{y}))]}{\text{number of unique permutations}} = \frac{1}{{10 \choose 5}} = 0.004 \]

\( s(\pi(\tilde{y})) = 67 \)

\( s(\pi(\tilde{y})) = 119 \)

\( s(\pi(\tilde{y})) = 7 \)

\( s(\tilde{y}) = 119 \)

\( \pi(\tilde{y}) \) is a permutation of \( \tilde{y} \)

Reject null hypothesis
Information Flow Experiments

Experimental Group
- Experimental Treatment
  (visit car-related sites)

Controlled Environment

Control Group
- Control Treatment
  (idle)

Ad Ecosystem

Measurements (ads)

Test Statistic

Hypothetical Value

Observed Value
A rigorous methodology for information flow experiments

• Connection between Information Flow and Causal Experiments

• Statistical principles for designing Information Flow Experiments
  – Control for known confounders
  – Randomize to break unknown confounders

• Significance testing with non-parametric statistical tests
Information Flow Experiments on Personalized Ads and Ad Settings
Ad Settings

<table>
<thead>
<tr>
<th>Ads on Google</th>
<th>Google ads across the web</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
<td><strong>Male</strong></td>
</tr>
<tr>
<td>N/A</td>
<td>Edit</td>
</tr>
<tr>
<td></td>
<td>Based on the websites you've visited</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td><strong>18-24</strong></td>
</tr>
<tr>
<td>N/A</td>
<td>Edit</td>
</tr>
<tr>
<td></td>
<td>Based on the websites you've visited</td>
</tr>
<tr>
<td><strong>Languages</strong></td>
<td><strong>None</strong></td>
</tr>
<tr>
<td>N/A</td>
<td>Edit</td>
</tr>
<tr>
<td></td>
<td>Based on the websites you've visited</td>
</tr>
<tr>
<td><strong>Interests</strong></td>
<td><strong>Bike Helmets &amp; Protective Gear, and 2 more</strong></td>
</tr>
<tr>
<td>N/A</td>
<td>Edit</td>
</tr>
<tr>
<td></td>
<td>Based on the websites you've visited</td>
</tr>
</tbody>
</table>

**Opt-out settings**
- Opt out of interest-based ads on Google
- Opt out of interest-based Google ads across the web
Model of Interactions

Web Browsing → Ad Ecosystem

Ad Ecosystem

Advertisements

Ad Settings

inferences

edits
Scaling Challenges

• Limited samples

• Selection of test statistic
AdFisher Methodology

- Experimental Treatment
- Control Treatment

Measurements

Significance Testing

$p$-value

Machine Learning

Classifier

Ad Ecosystem

Block 1

Block n

Training Data

Measurements

explanations
We study three properties on the Ad Ecosystem

• Discrimination

• Transparency

• Choice
Discrimination

Web Browsing

Ad Ecosystem

Advertisements

Browse websites related to finding jobs

Ad Settings

Set gender bit

Significant causal effect on ads
(p-value < 0.00003)
Discrimination Explanations

Female Group

Jobs (Hiring Now)
www.jobsinyourarea.co
45 vs. 8

4Runner Parts Service
www.westernpatoyotaservice.com
36 vs. 5

Criminal Justice Program
www3.mc3.edu/Criminal+Justice
29 vs. 1

Male Group

$200k+ Jobs - Execs Only
careerchange.com
311 vs. 1816

Find Next $200k+ Job
careerchange.com
7 vs. 36

Become a Youth Counselor
www.youthcounseling.degreelap.com
0 vs. 310
Transparency

Visit the top 100 **substance abuse** sites

Ad Ecosystem

Ad Settings

Web Browsing

Advertisements

**No effect** on ad settings

Significant causal effect on ads
(p-value < 0.00005)
## Transparency Explanations

<table>
<thead>
<tr>
<th>Substance Abuse Visitors</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Watershed Rehab</td>
<td>Alluria Alert</td>
</tr>
<tr>
<td><a href="http://www.thewatershed.com/Help">www.thewatershed.com/Help</a></td>
<td><a href="http://www.bestbeautybrand.com">www.bestbeautybrand.com</a></td>
</tr>
<tr>
<td>2276 vs. 0</td>
<td>0 vs. 9</td>
</tr>
<tr>
<td>Watershed Rehab</td>
<td>Best Dividend Stocks</td>
</tr>
<tr>
<td><a href="http://www.thewatershed.com/Rehab">www.thewatershed.com/Rehab</a></td>
<td><a href="http://www.dividends.wyattresearch.com">www.dividends.wyattresearch.com</a></td>
</tr>
<tr>
<td>362 vs. 0</td>
<td>24 vs. 54</td>
</tr>
<tr>
<td>The Watershed Rehab</td>
<td>10 Stocks to Hold Forever</td>
</tr>
<tr>
<td>(none)</td>
<td><a href="http://www.streetauthority.com">www.streetauthority.com</a></td>
</tr>
<tr>
<td>771 vs. 0</td>
<td>76 vs. 118</td>
</tr>
</tbody>
</table>
Additional notice on Ad Settings

Before

We use interests from your activity on websites to tailor ads to you. How it works.

After

Your activity on websites is used to serve interest based ads.

These categories can only control some of the Google ads you see. For instance, the interests listed here do not reflect ads selected based on a visit to a specific advertiser’s page (remarketing) or ads selected by other advertising providers and delivered by Google’s ad platforms. How it works.
Choice

Web Browsing → Ad Ecosystem → Advertisements

Visit sites related to online dating

Ad Settings

Remove interests related to online dating

Causes significant reduction in dating ads (p-value < 0.05)
Choice Explanations

**Keep Dating Interest**

- Are You Single?
  - www.zoosk.com/Dating
  - 2433 vs. 78

- Top 5 Online Dating Sites
  - www.consumer-rankings.com/Dating
  - 408 vs. 13

- Why can't I find a date?
  - www.gk2gk.com
  - 51 vs. 5

**Remove Dating Interest**

- Car Loans w/ Bad Credit
  - www.car.com/Bad-Credit-Car-Loan
  - 8 vs. 37

- Individual Health Plans
  - www.individualhealthquotes.com
  - 21 vs. 46

- Crazy New Obama Tax
  - www.endofamerica.com
  - 22 vs. 51
Possible Impact on Ad Settings

Control your Google ads
You can control the ads that are delivered to you based on your Google Account, across devices, by editing these settings. These ads are more likely to be useful and relevant to you.

Your interests
- Action & Adventure Films
- Dance & Electronic Music
- Indie & Alternative Music
- Online Video
- Recording Industry
- TV Comedies
- Arts & Entertainment
- Drama Films
- Music & Audio
- Pianos & Keyboards
- Reference
- Vocals & Show Tunes
- Concerts & Music Festivals
- Fitness
- Music Videos
- Pop Music
- Reggaeton
- Cricket

Your Google profile
Gender
Age 25–34
Possible Impact on Ad Settings

Control your Google ads

You can control the ads that are delivered to you based on anonymous information by editing these settings. These ads will more likely be useful and relevant to you and your Google services, such as search.

Please set your ads preference
Ads based on your interests can be switched on or off.

Ads based on your interests on websites beyond google.com

**With Ads based on your interests ON**
- You can mute some ads that you don't want to see
- You may see ads related to factors such as your interests and previous visits to other websites (remarketing)
- The ads may be based on anonymous demographic details such as age and gender
- The ads may be based on your general location (such as city or state) or the current page or app you are looking at

**With Ads based on your interests OFF**
- You will still see ads
- The ads will be less relevant to you
- You will be opted-out of interest based ads that are part of the Google Display Network and Google ads that are based on visits to advertiser websites (remarketing)
- The ads may be based on your general location (such as city or state) or the current page or app you are looking at
Conclusions

1. Findings of discrimination, lack of transparency, and choice.

2. Scalable methodology
   • Blocked design
   • Automated selection of test statistic

3. AdFisher is freely available online: 
   github.com/tadatitam/info-flow-experiments