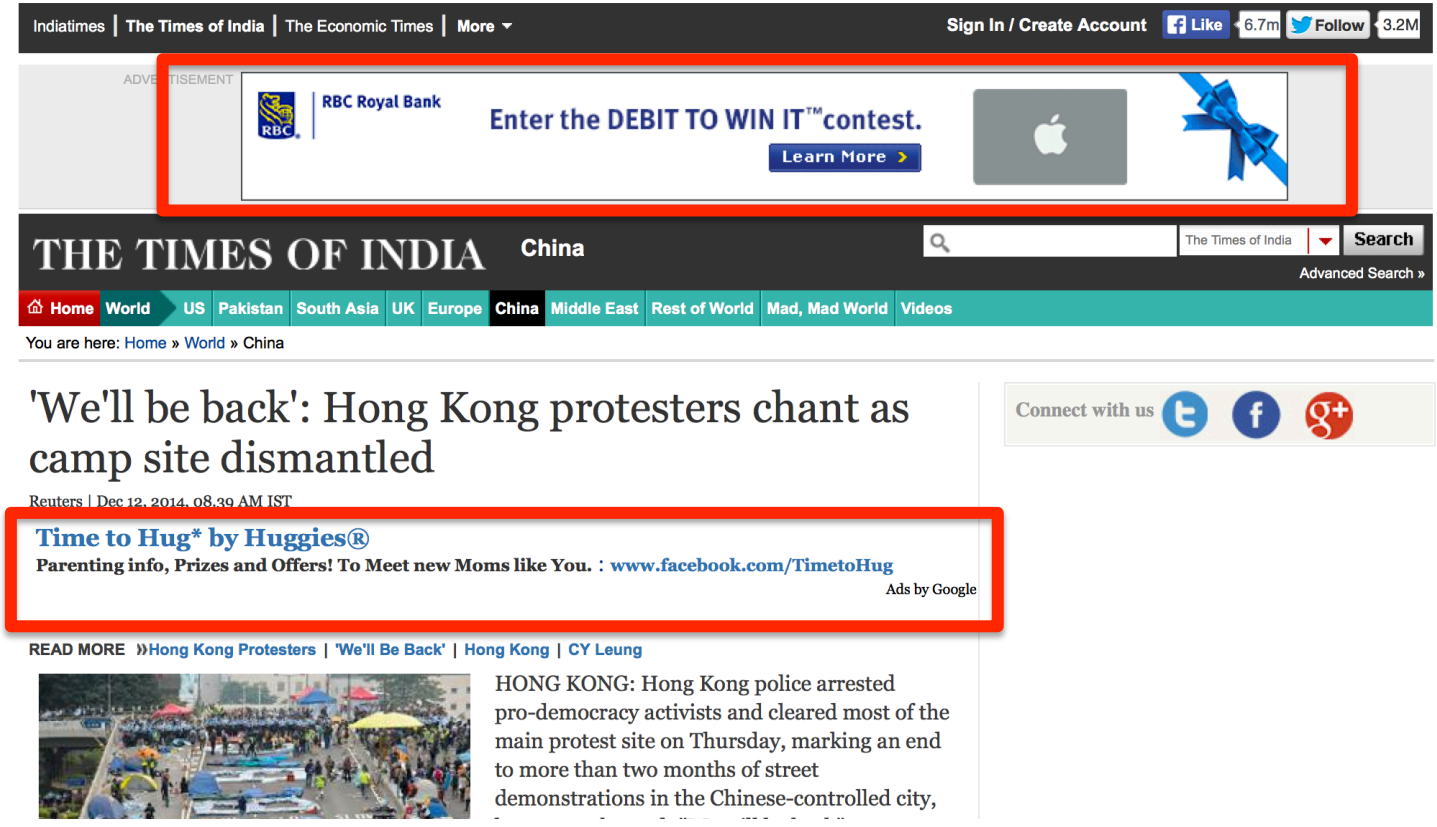
Information Flow Experiments Methodology

Personalized Web Advertising



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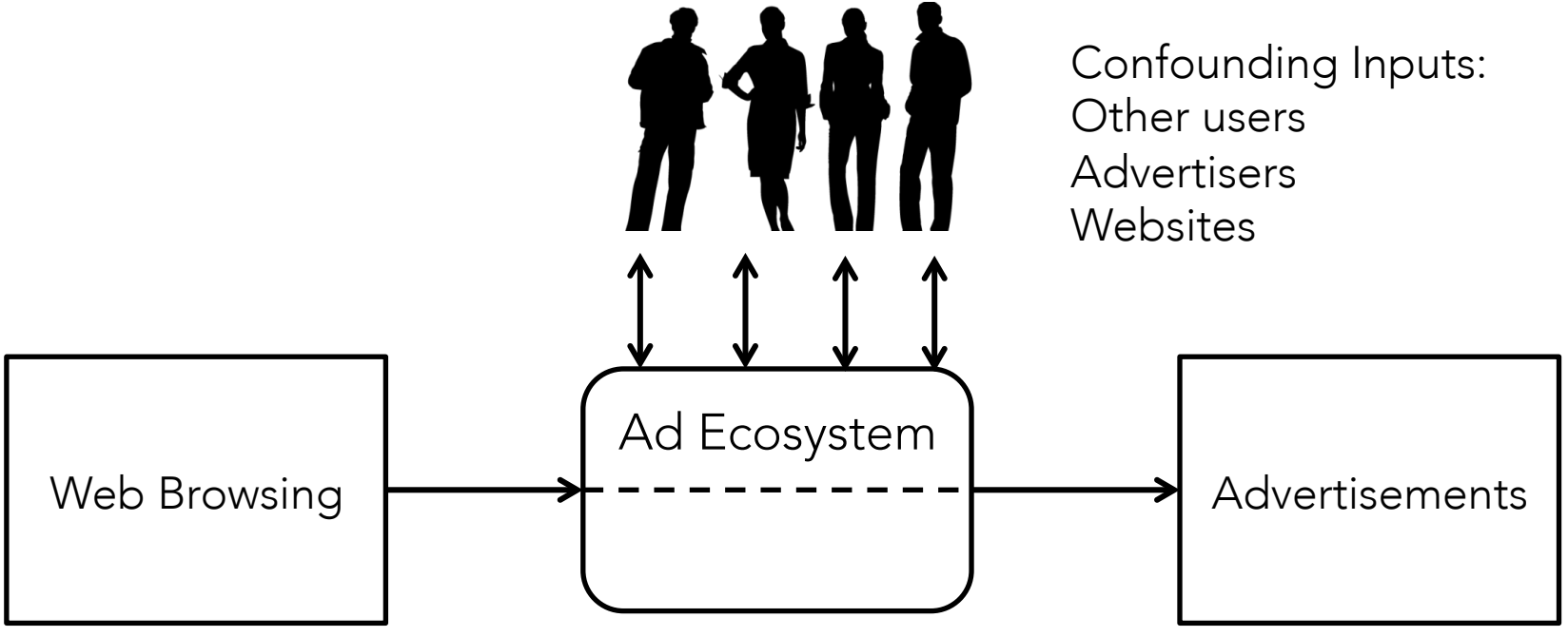
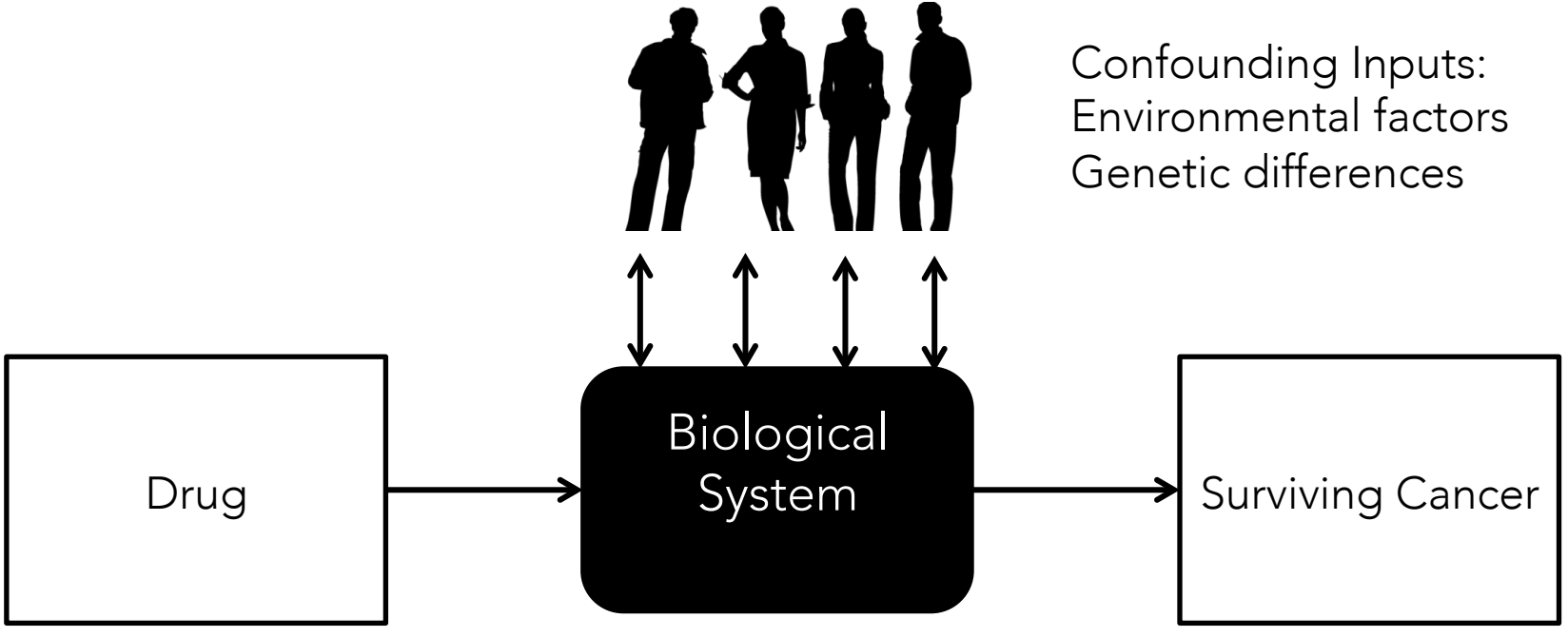


Experimental Design



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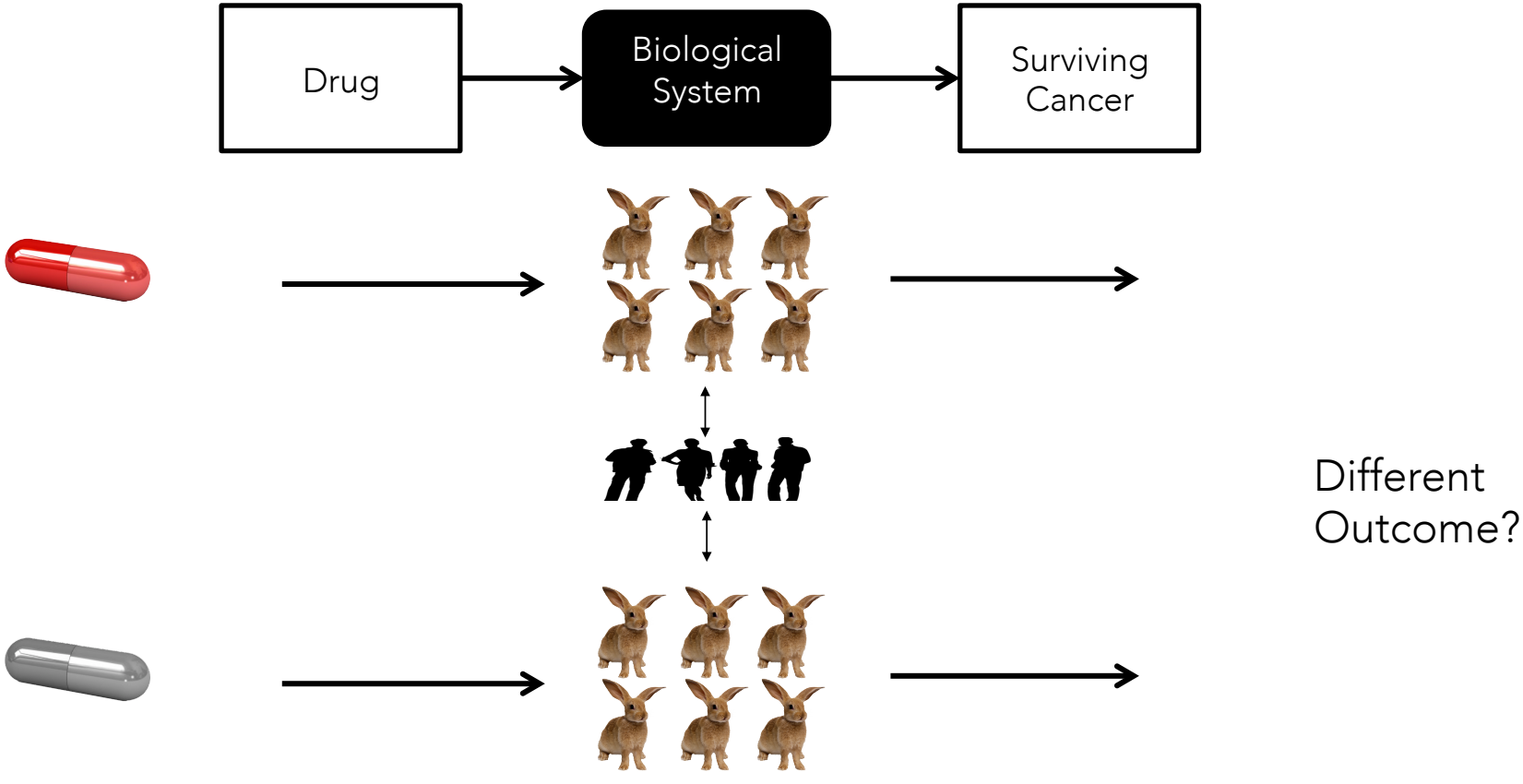
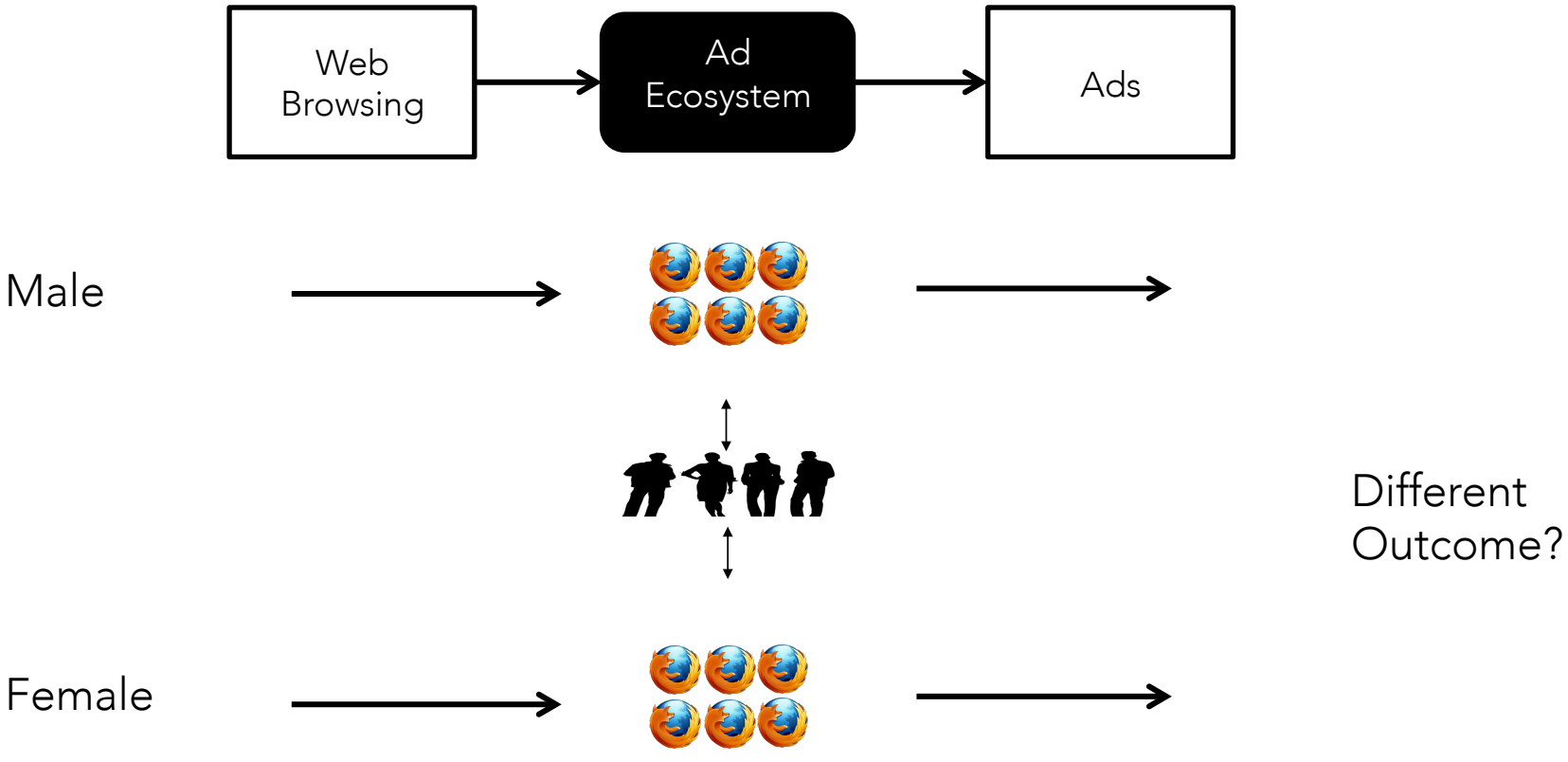
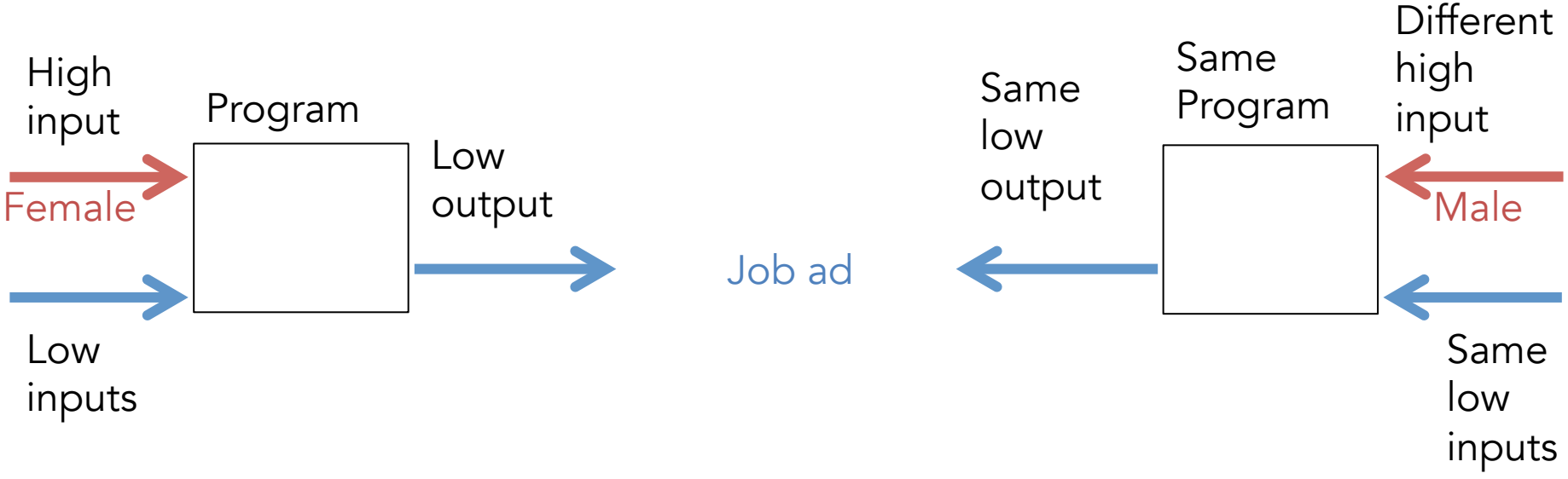


Information Flow Experiments

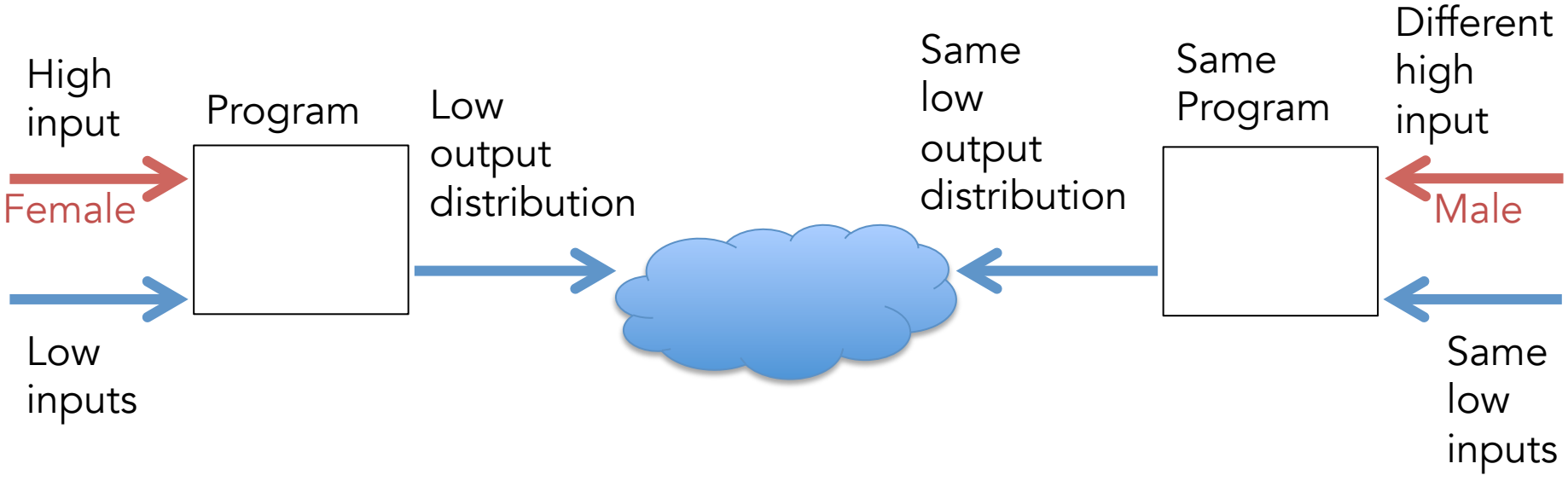


[Goguen and Meseguer, 1982]

Noninterference



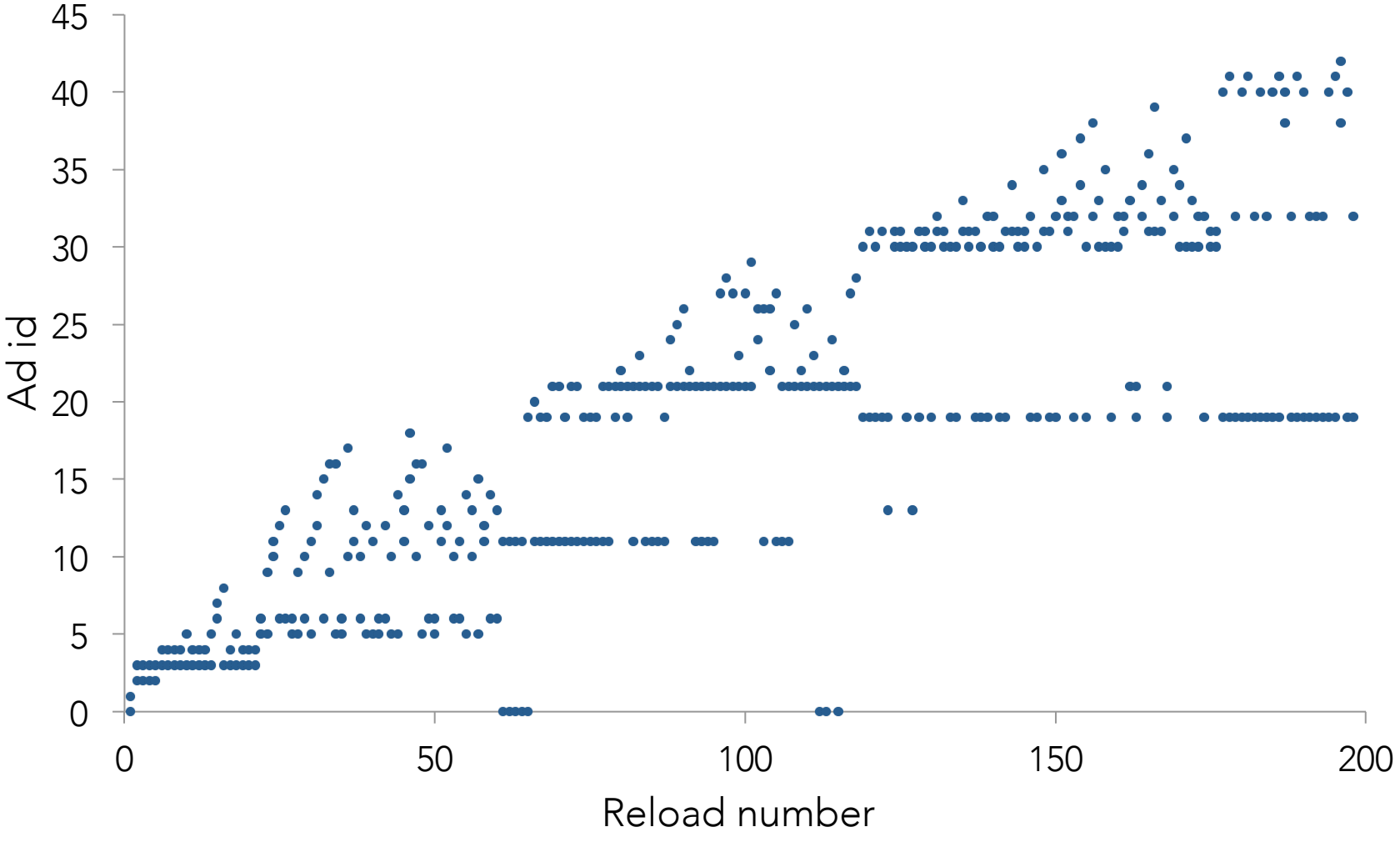
Probabilistic Noninterference



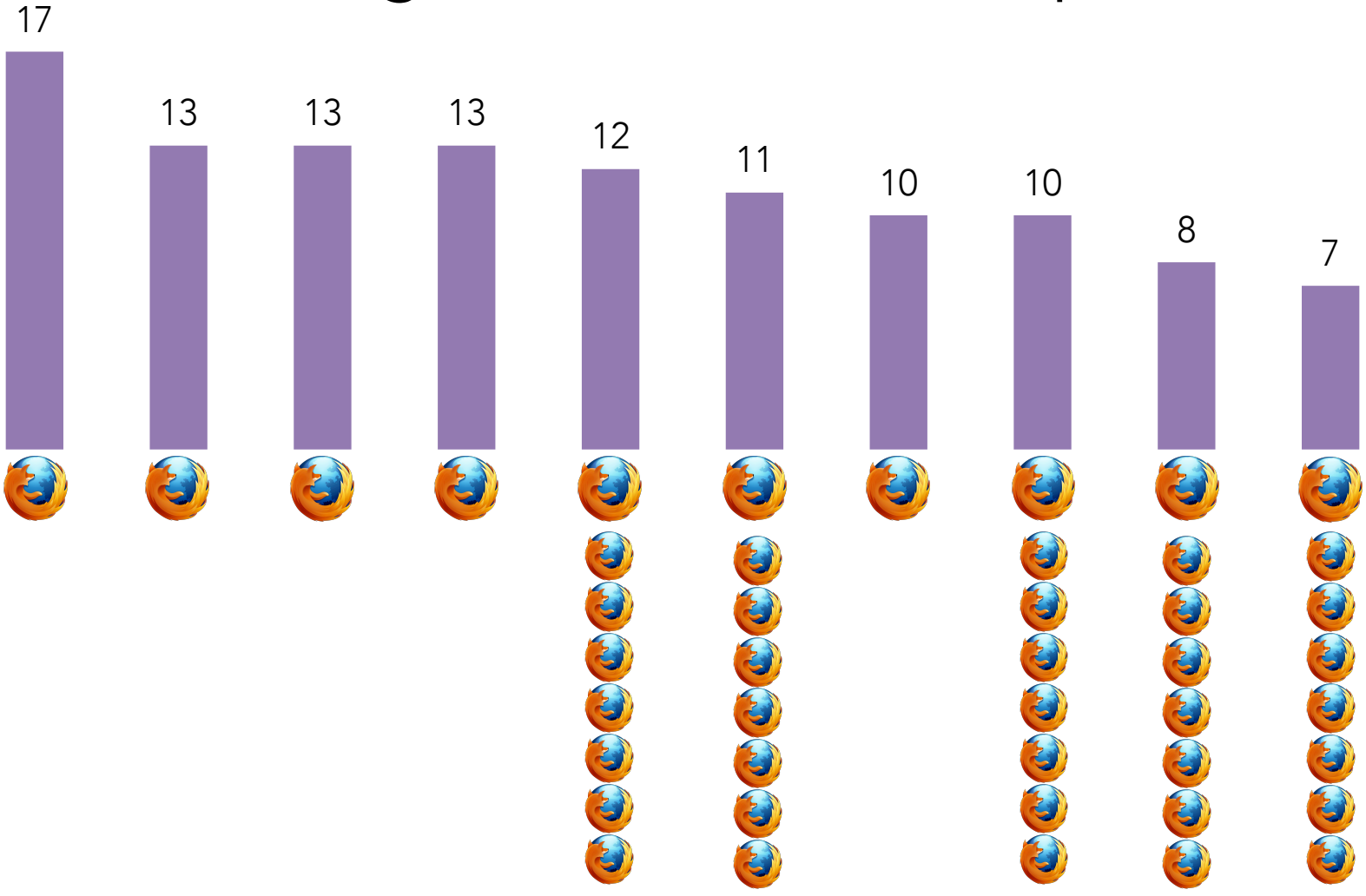
Information Flow Experiments as Science

Experimental Science	Information Flow
Natural process	System in question
Population of units	Subset of interactions
Treatments	Inputs
Responses	Outputs
…	…
Causation	Information flow

Mechanism of ad delivery is complex



Browser Agents are not Independent

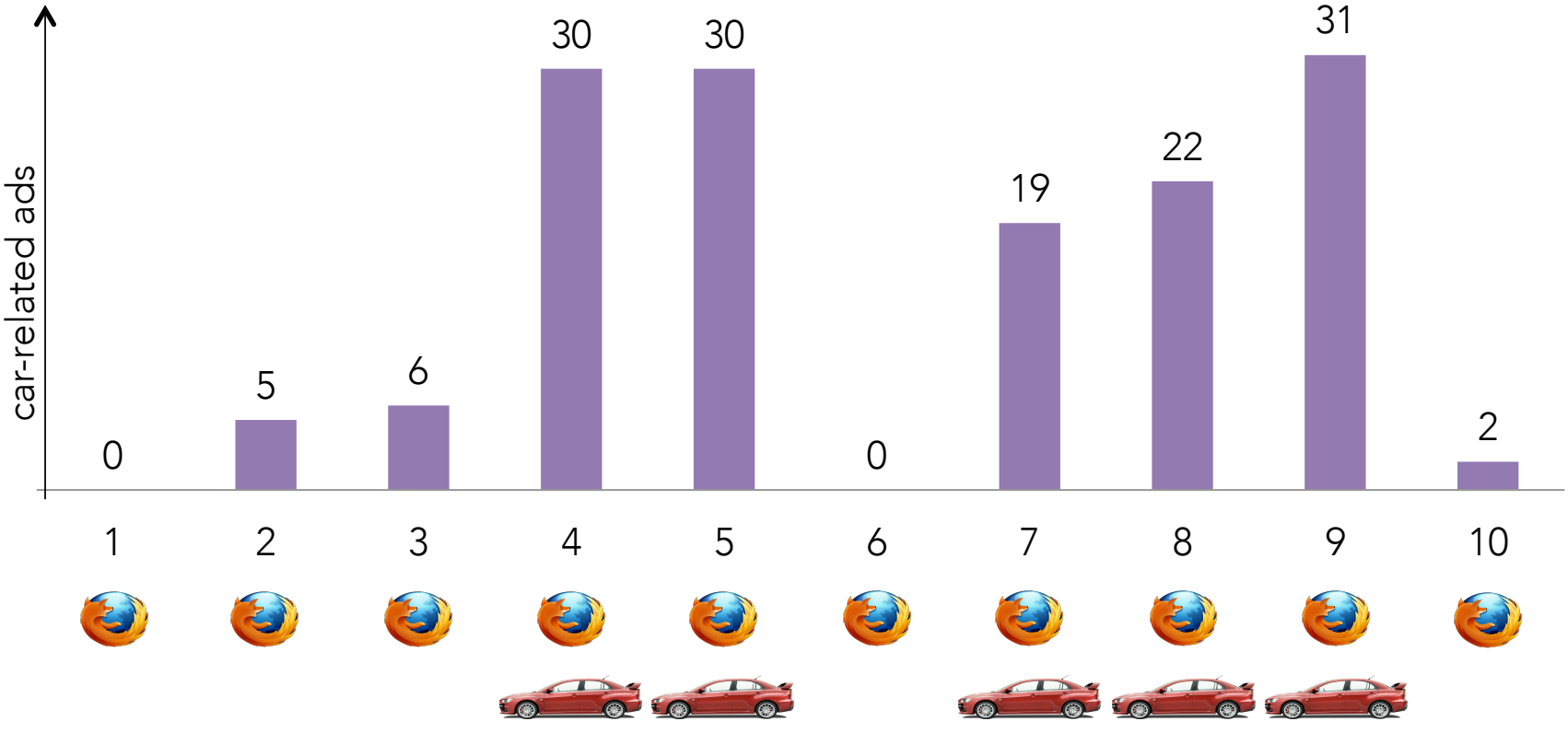


Our Idea:

- 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: Example



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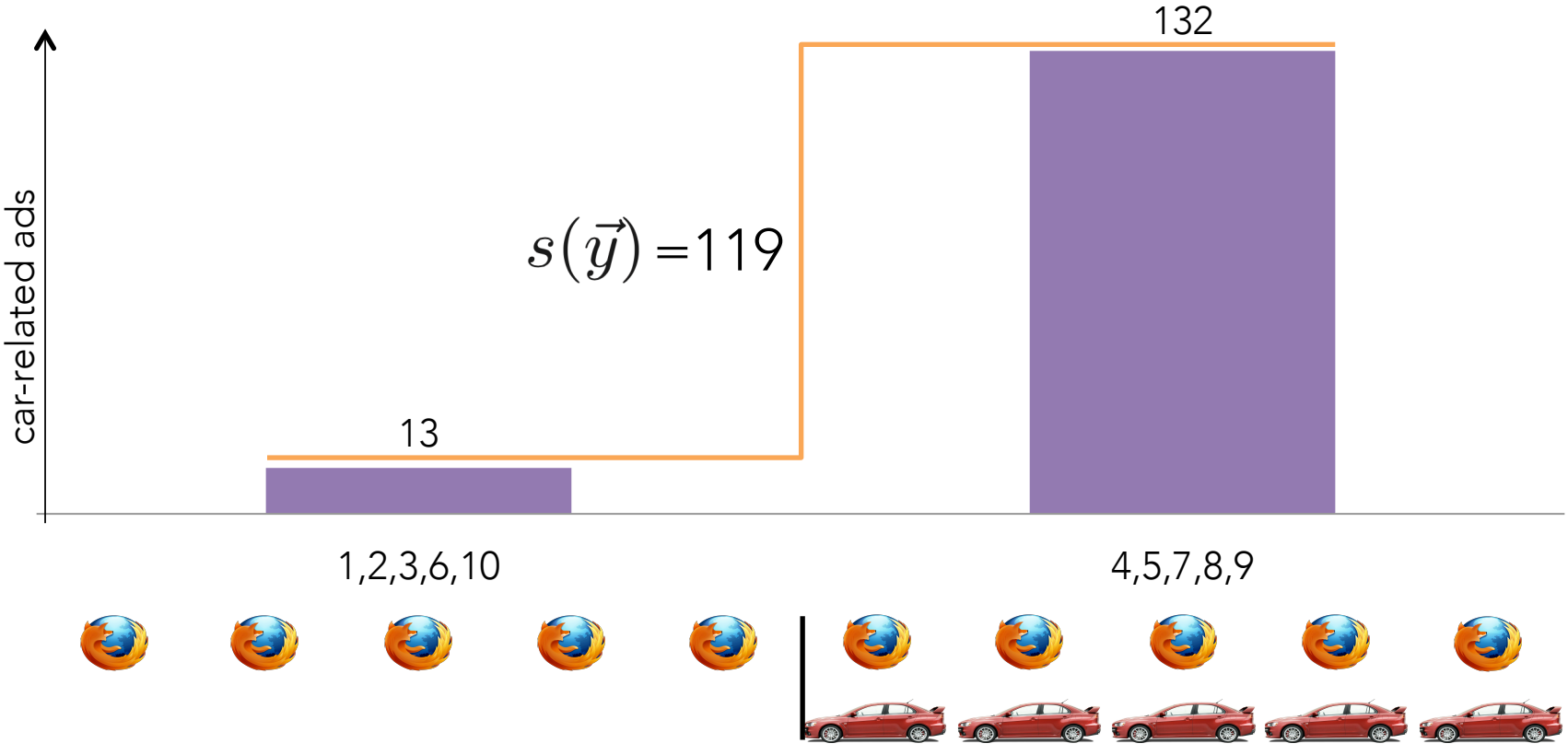
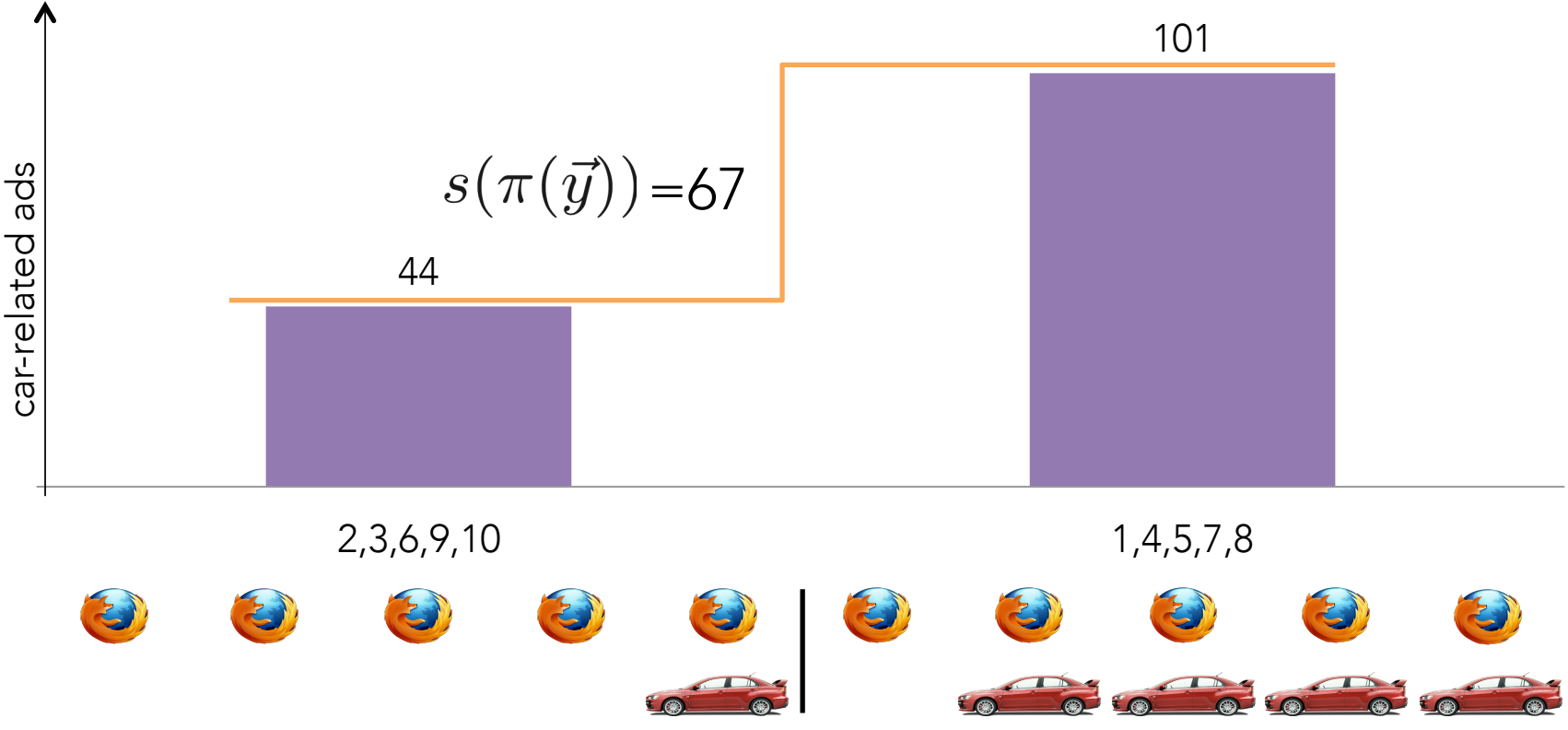


$\vec{y}$ is the measurement vector

$s(\vec{y})$ is the statistic computed over $\vec{y}$

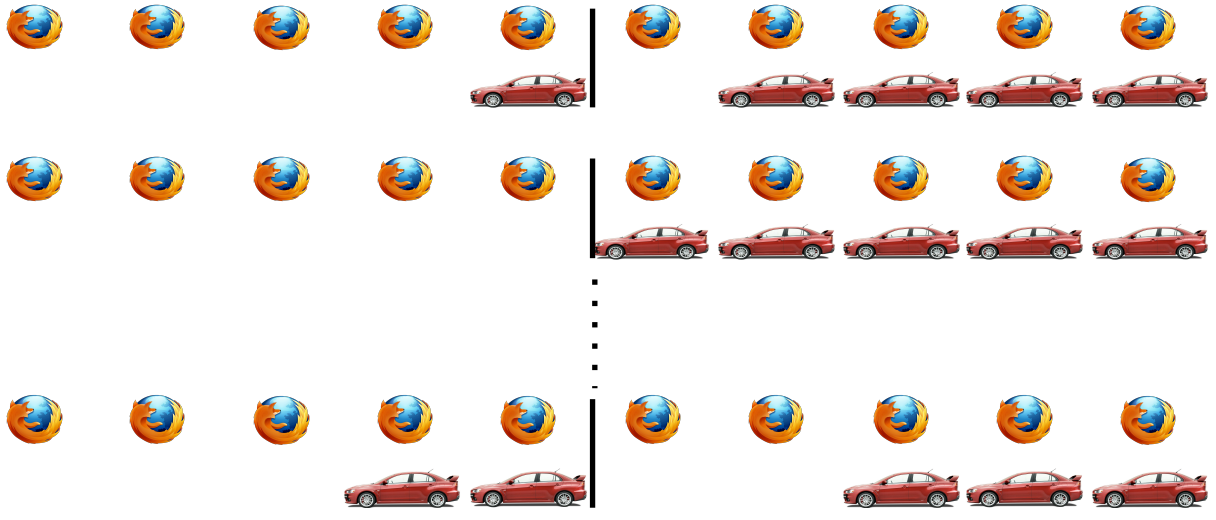
Permutation Test: Example



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

$s(\vec{y})$ is the statistic computed over $\vec{y}$

Permutation Test: Example



$s(\pi(\vec{y}))$ =67

$s(\pi(\vec{y}))$ =119

$s(\pi(\vec{y}))$ =7

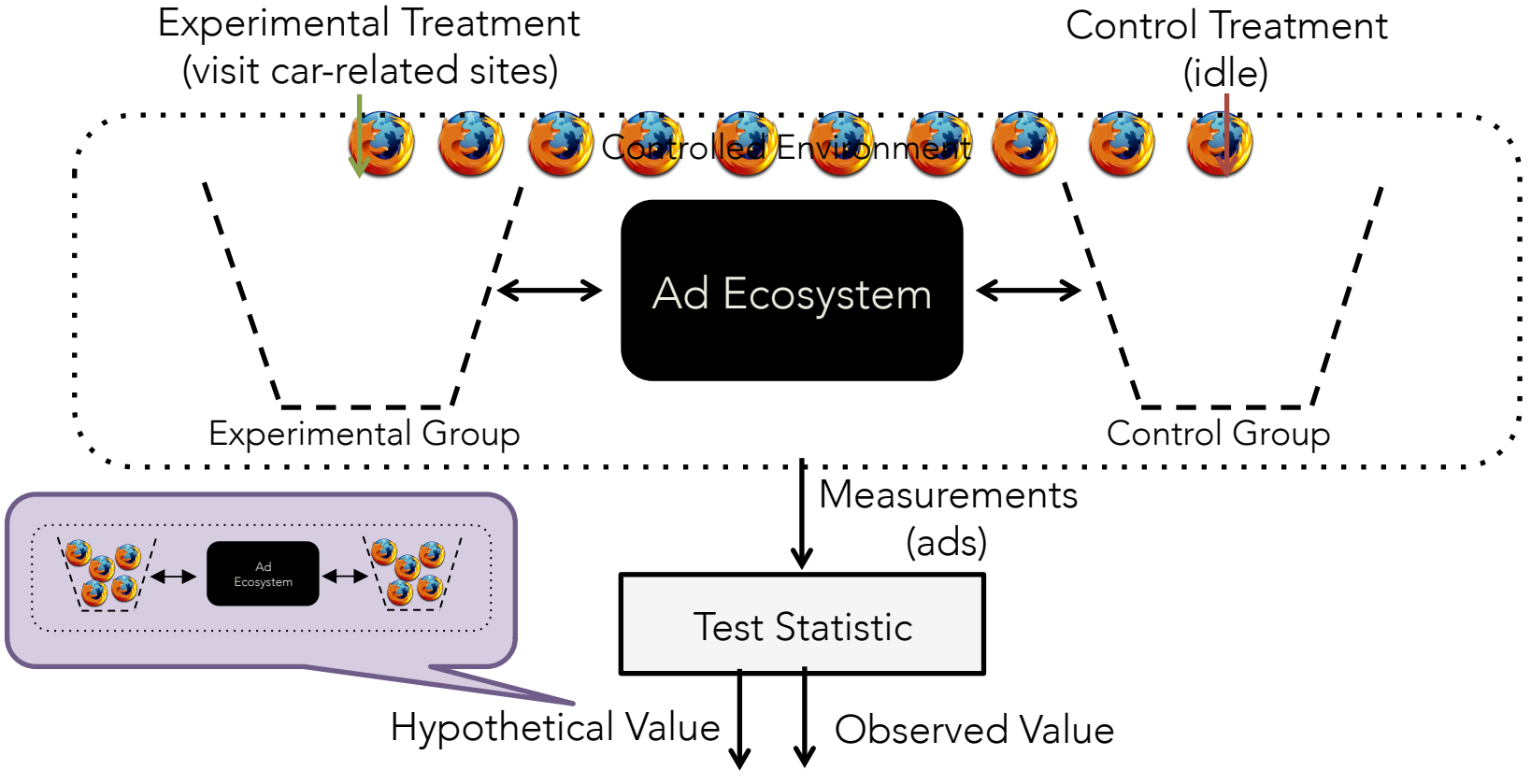
$s(\vec{y})$ = 119

$$\text{p-value} = \frac{\text{count}\left[s(\vec{y}) \leq s(\pi(\vec{y}))\right]}{\text{number of unique permutations}} = \frac{1}{{}^{10}C_5} = 0.004$$

Reject null hypothesis

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

Information Flow Experiments



A rigorous methodology for information flow experiments

- Connection between Information Flow and Causal Experiments

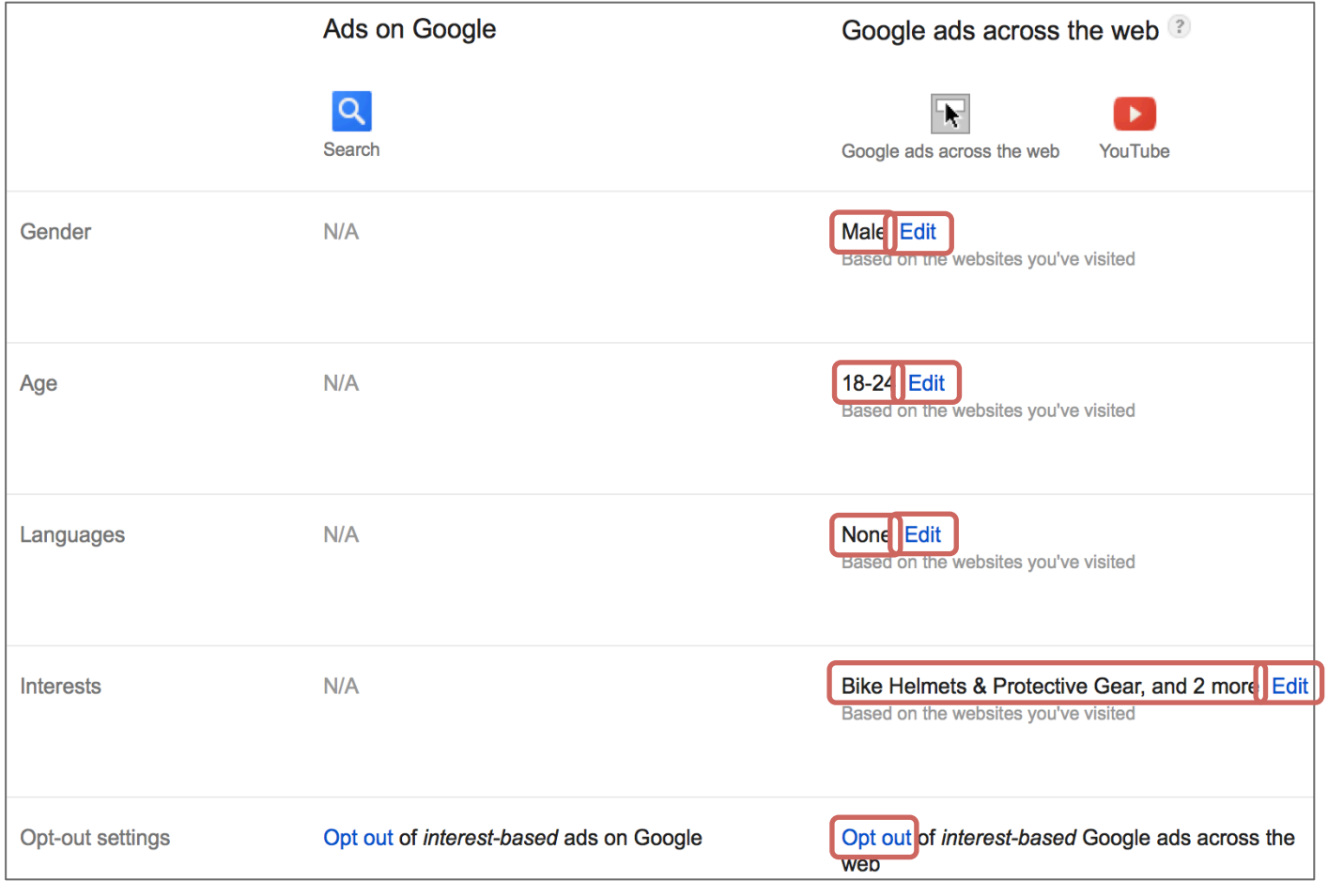
- Statistical principles for designing Information Flow Experiments
  - Control for known confounders
  - Randomize to break unknown confounders

- Significance Testing with non-parametric statistical tests

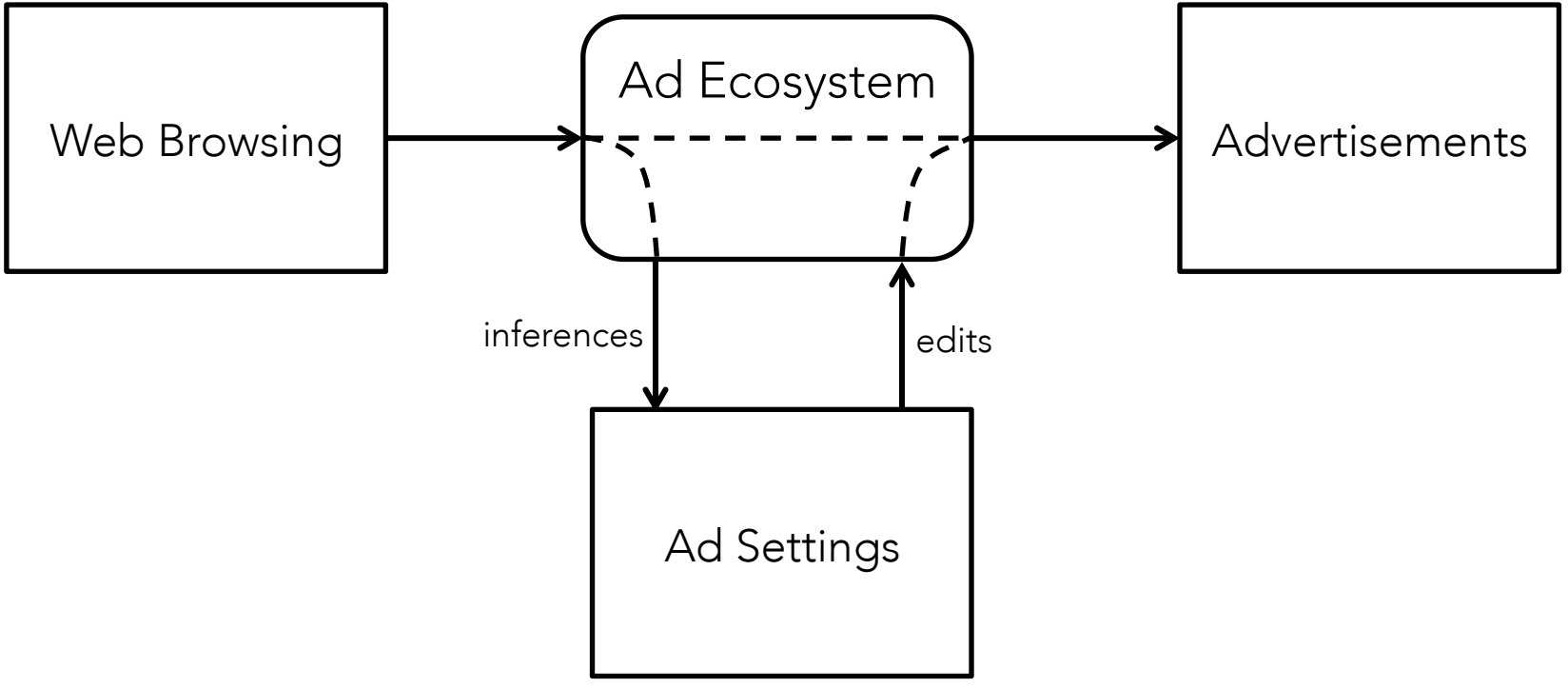
Information Flow Experiments on Personalized Ads and Ad Settings

Ad Settings

www.google.com/settings/ads



Model of Interactions



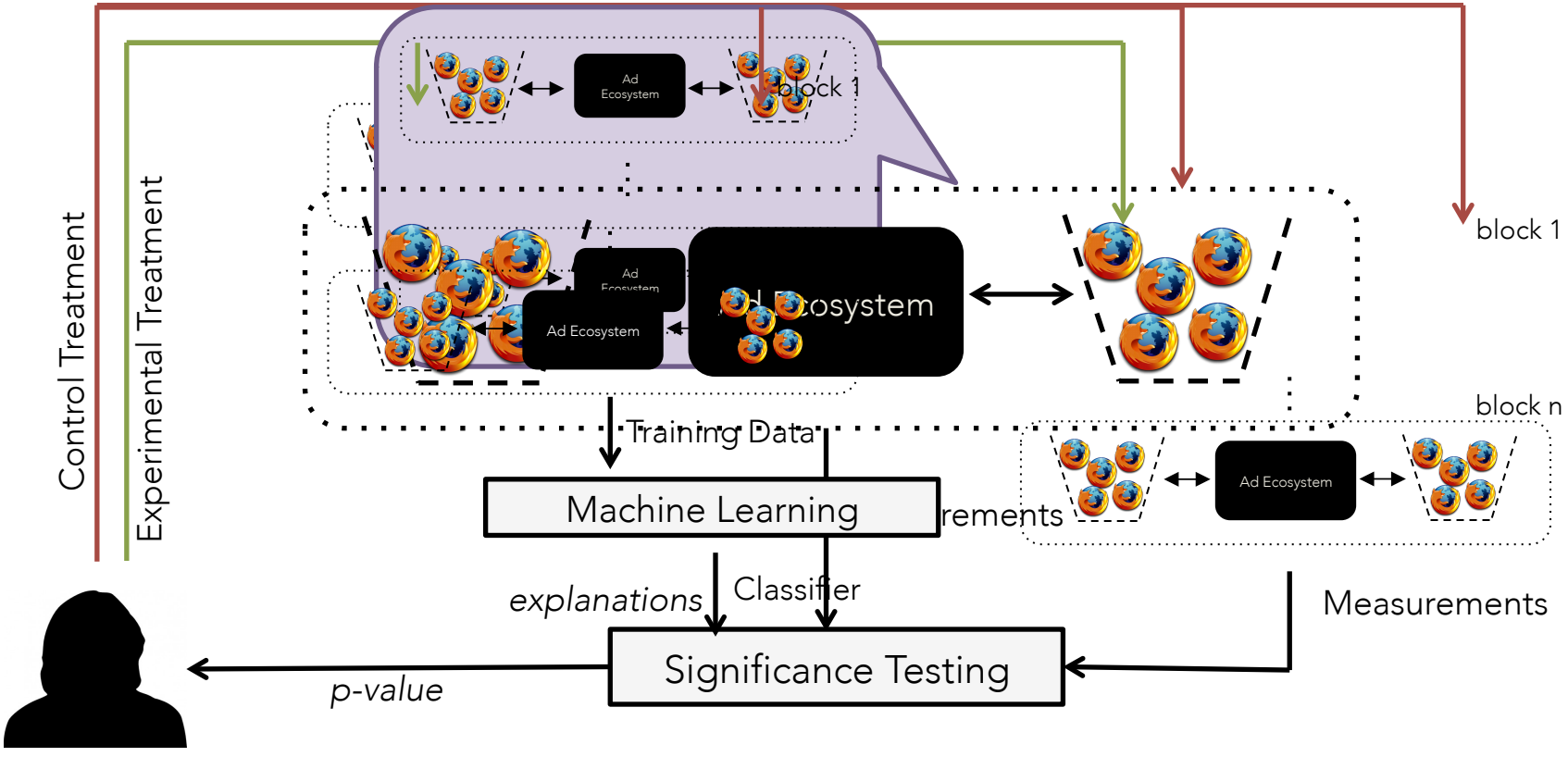
Scaling Challenges

- Limited samples

- Selection of test statistic

Test Statistic

AdFisher Methodology



We study three properties on the Ad Ecosystem

- Discrimination
- Transparency
- Choice

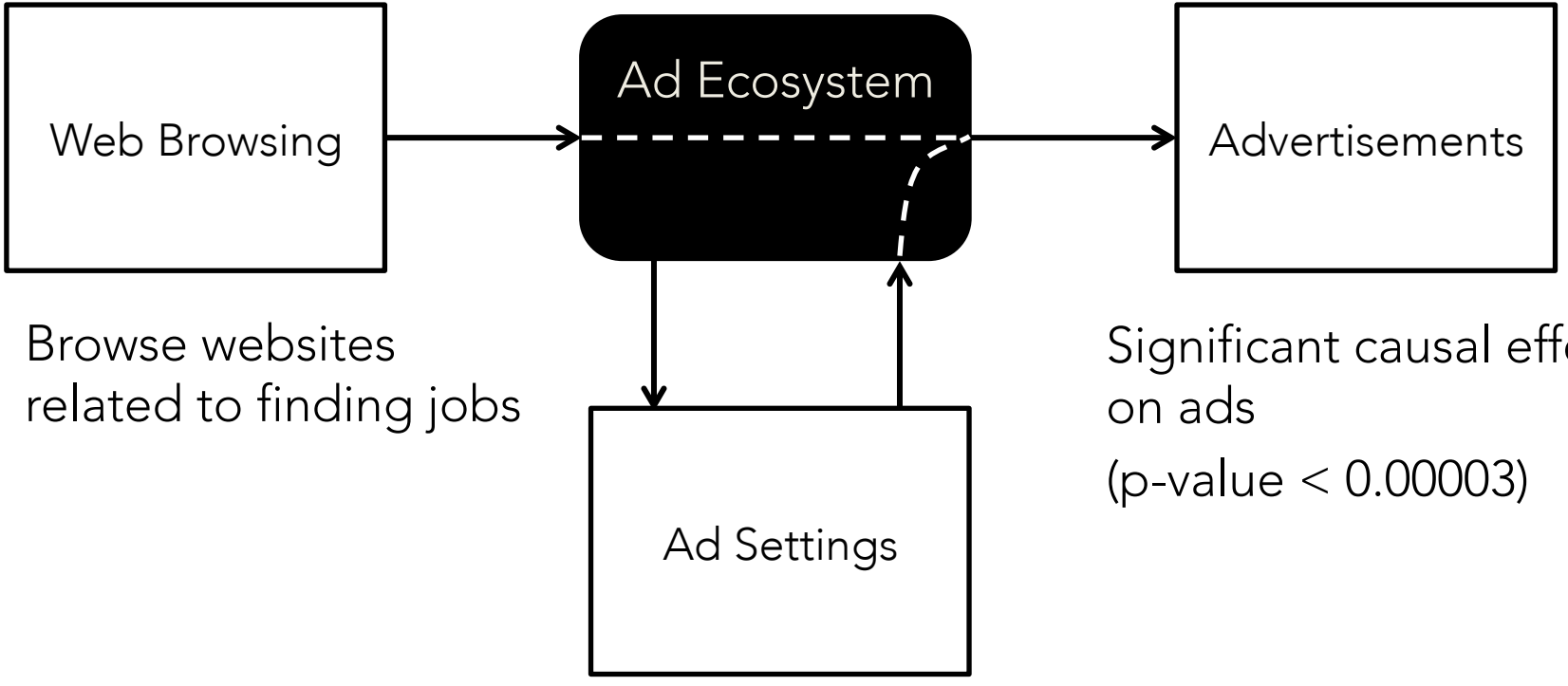
We developed and used AdFisher to run Information Flow Experiments

- Emulates users with fresh browser instances.
- Randomized assignment.
- Statistical analysis to find causal relations.

Part I: Findings

Part II: Methodology and Tool

Discrimination



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

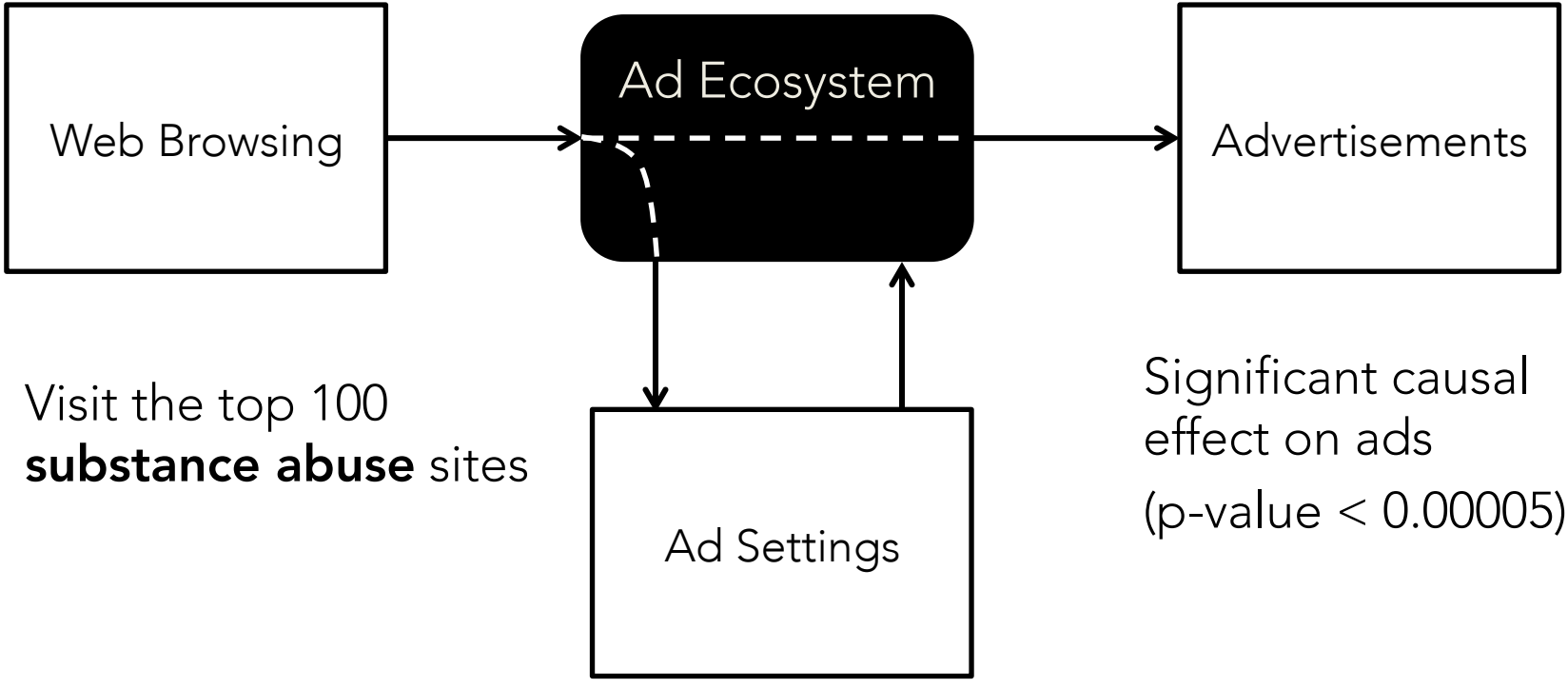
Find Next $200k+ Job
careerchange.com
7 vs. 36

Become a Youth Counselor
www.youthcounseling.degreeleap.com
0 vs. 310

We are not claiming

- Generalization
  - Experiments performed from one IP address in Pittsburgh.
- Policy or Legal Violations
  - Google allows gender based targeting.
- Completeness
  - We might not have found every effect.

Transparency



Visit the top 100 **substance abuse** sites

Significant causal effect on ads

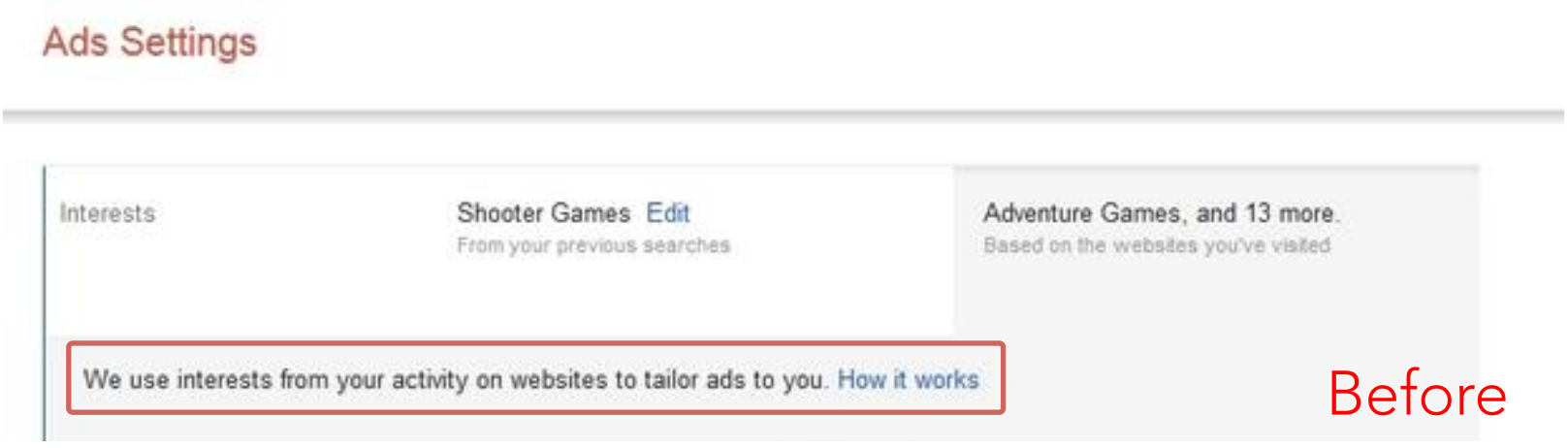
(p-value < 0.00005)

No effect on ad settings

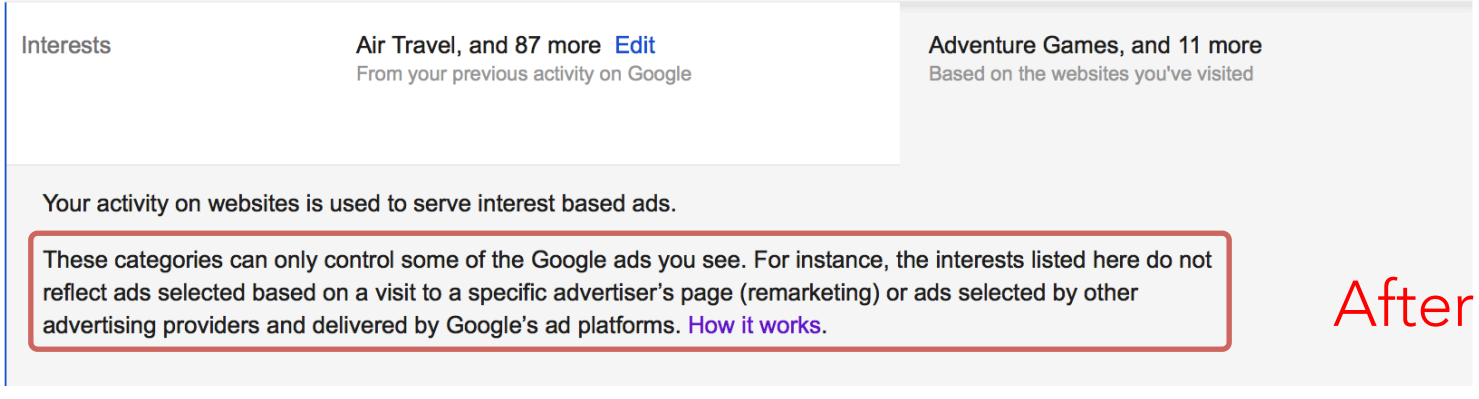
Transparency Explanations

Substance Abuse Visitors	Control Group
The Watershed Rehab www.thewatershed.com/Help 2276 vs. 0	Alluria Alert www.bestbeautybrand.com 0 vs. 9
Watershed Rehab www.thewatershed.com/Rehab 362 vs. 0	Best Dividend Stocks dividends.wyattresearch.com 24 vs. 54
The Watershed Rehab (none) 771 vs. 0	10 Stocks to Hold Forever www.streetauthority.com 76 vs. 118

Additional notice on Ad Settings

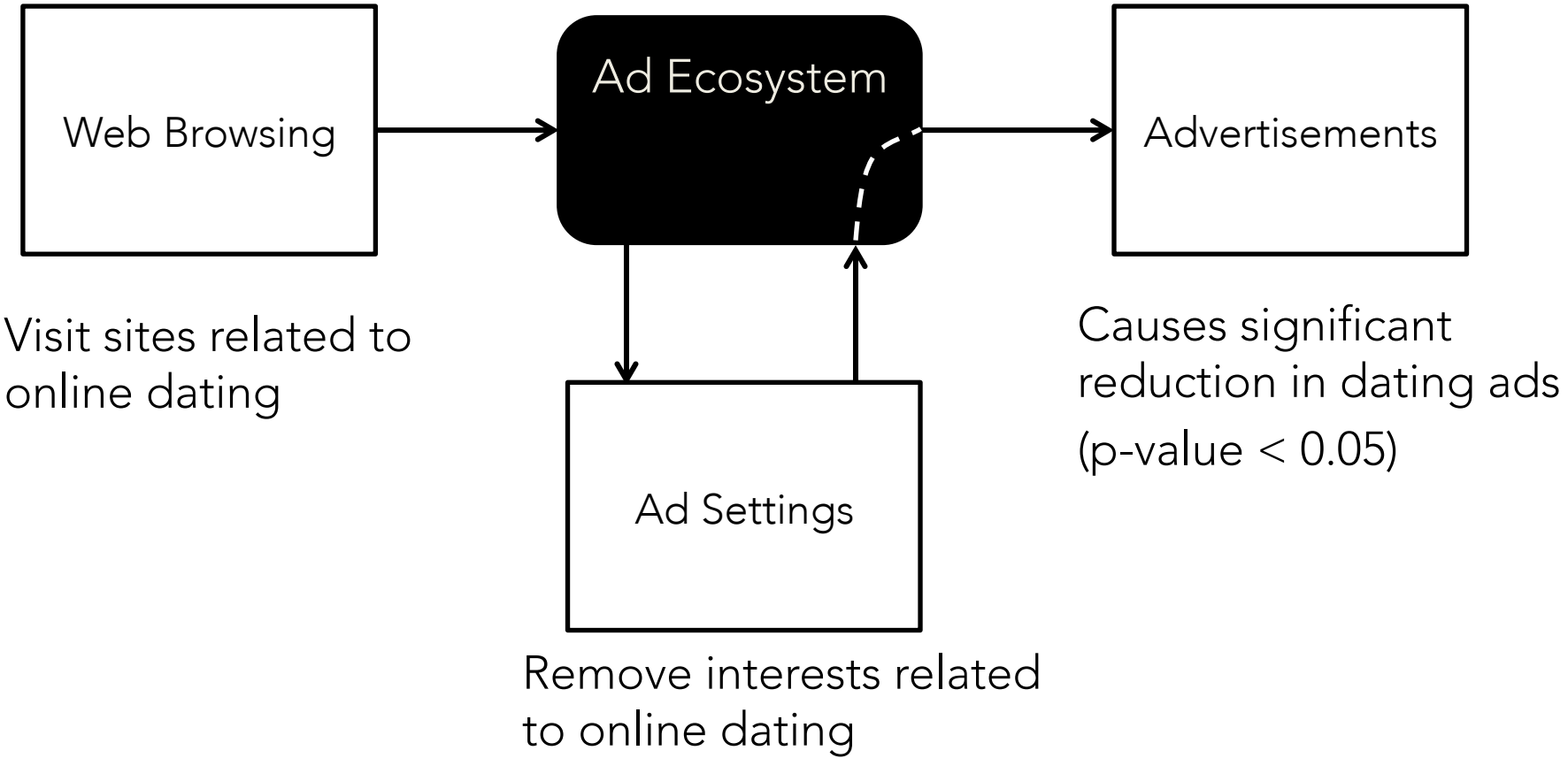


Before



After

Choice


Web Browsing
Ad Ecosystem
Advertisements
Visit sites related to online dating
Causes significant reduction in dating ads
(p-value < 0.05)
Ad Settings
Remove interests related to online dating

Choice Explanations

Keeping 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

Removing 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

Part I: Findings

Part II: Methodology and Tool

Prior Work on Behavioral Marketing

- No statistical significance
  - Guha+10
  - Balebako+12
  - Wills & Tatar 12
  - Liu+13 AdReveal
- Assumptions about ads
  - Barford+14 AdScape
  - Lecuyer+14 XRay
  - Englehardt+14 OpenWPM

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

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

+ ADD NEW INTEREST WHERE DID THESE COME FROM?

Your Google profile

Gender

25–34

Age

Ads based on your interests

Improve your ad experience when you are signed in to Google sites

ON

With Ads based on your interests ON	With Ads based on your interests OFF
• The ads you see will be delivered based on your prior search queries, the videos you've watched on YouTube, as well as other information associated with your account, such as your age range or gender • On some Google sites like YouTube, you will see ads related to your interests, which you can edit at any time by visiting this page • You can block some ads that you don't want to see	• You will still see ads and they may be based on your general location (such as city or state) • Ads will not be based on data Google has associated with your Google Account, and so may be less relevant • You will no longer be able to edit your interests • All the advertising interests associated with your Google Account will be deleted

Control ads on 2 million+ websites

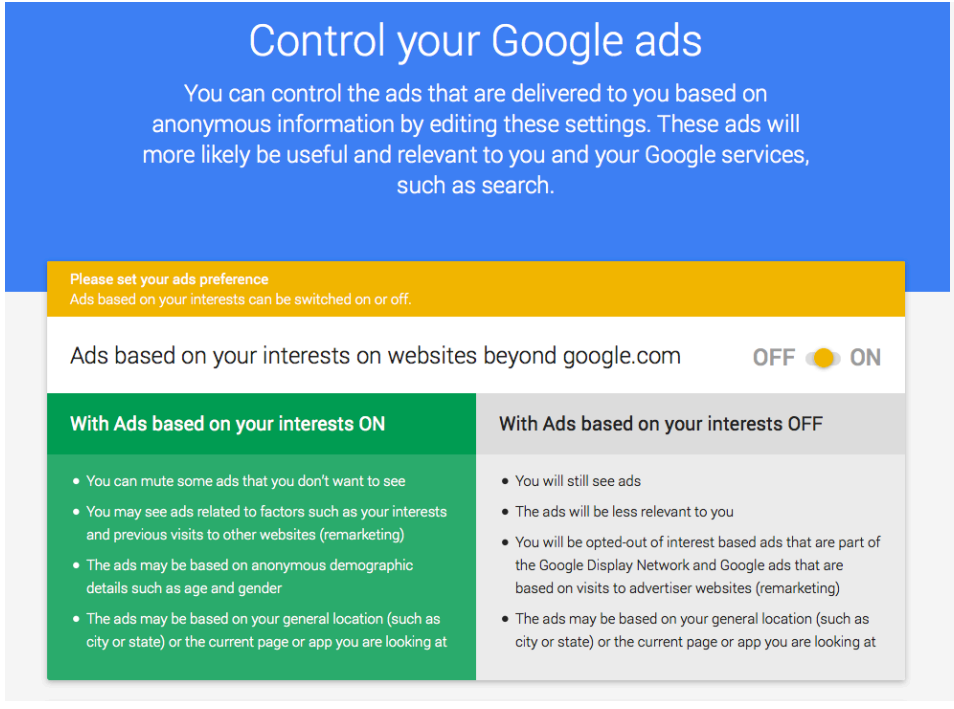
You can opt-out of and control more ads, such as:

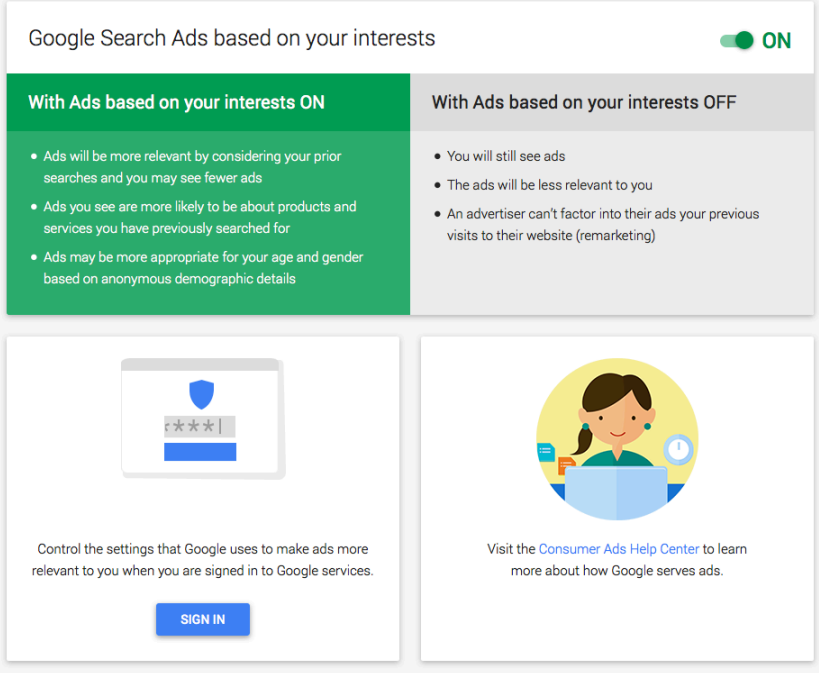
- ads shown anonymously to this browser by Google
- ads shown to you on non-Google sites
- ads that use information from your visits to advertiser websites
- ads shown to you on Google sites when you are not signed in

CONTROL SIGNED OUT ADS

Visit the Consumer Ads Help Center to learn more about how Google serves ads.

Possible Impact on Ad Settings





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

Future Work

- Extensions of AdFisher
- Assigning blame
- Internal auditing and preventing violations

Information Flow Experiments on Personalized Ads and Ad Settings

Amit Datta, CMU
Michael Tschantz, ICSI
Anupam Datta, CMU

INTERNATIONAL COMPUTER SCIENCE INSTITUTE

CyLab
Carnegie Mellon University

Backup Slides

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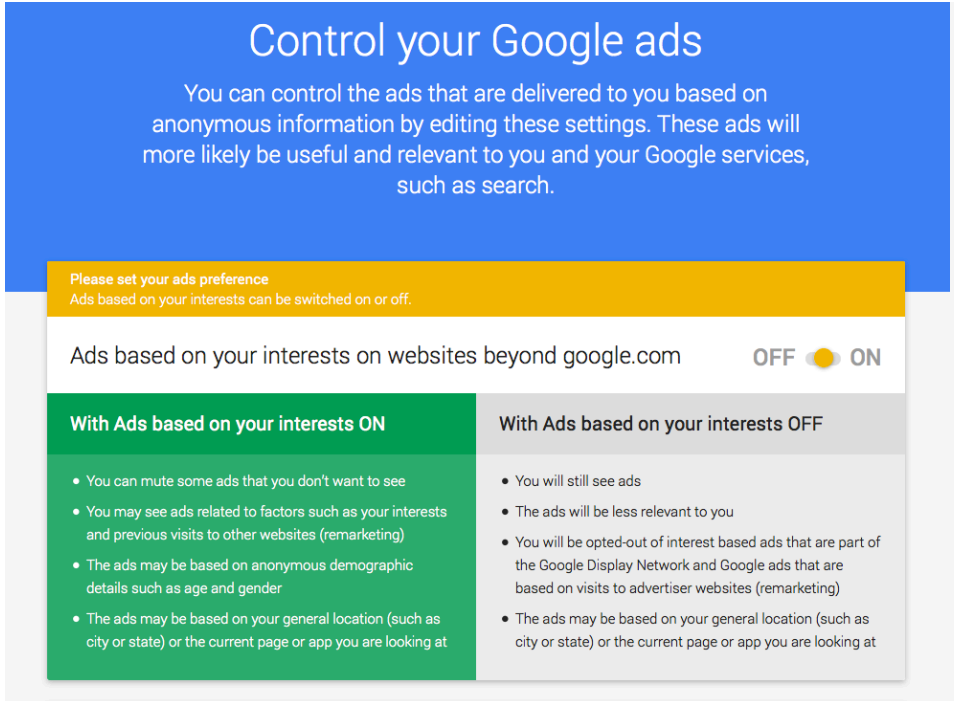

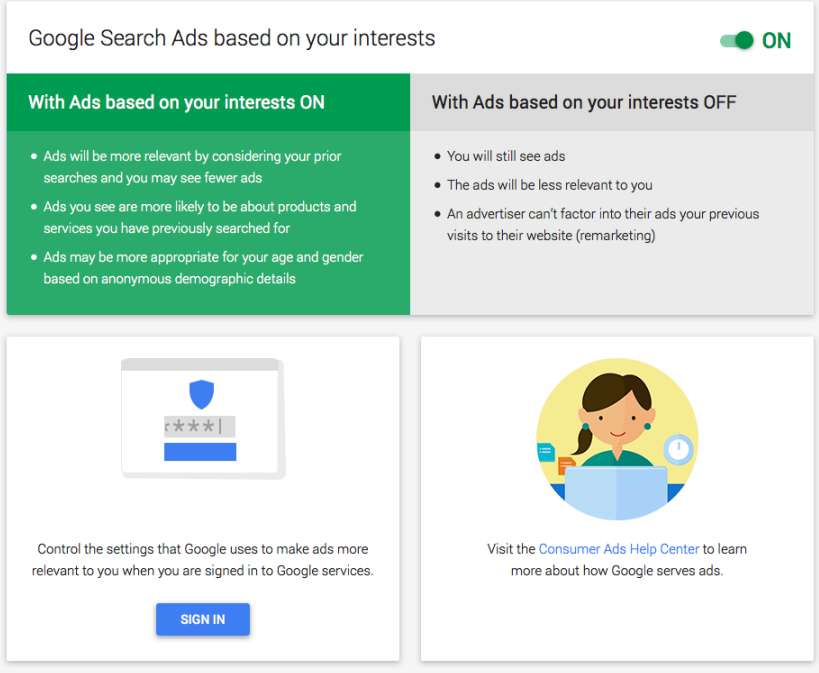

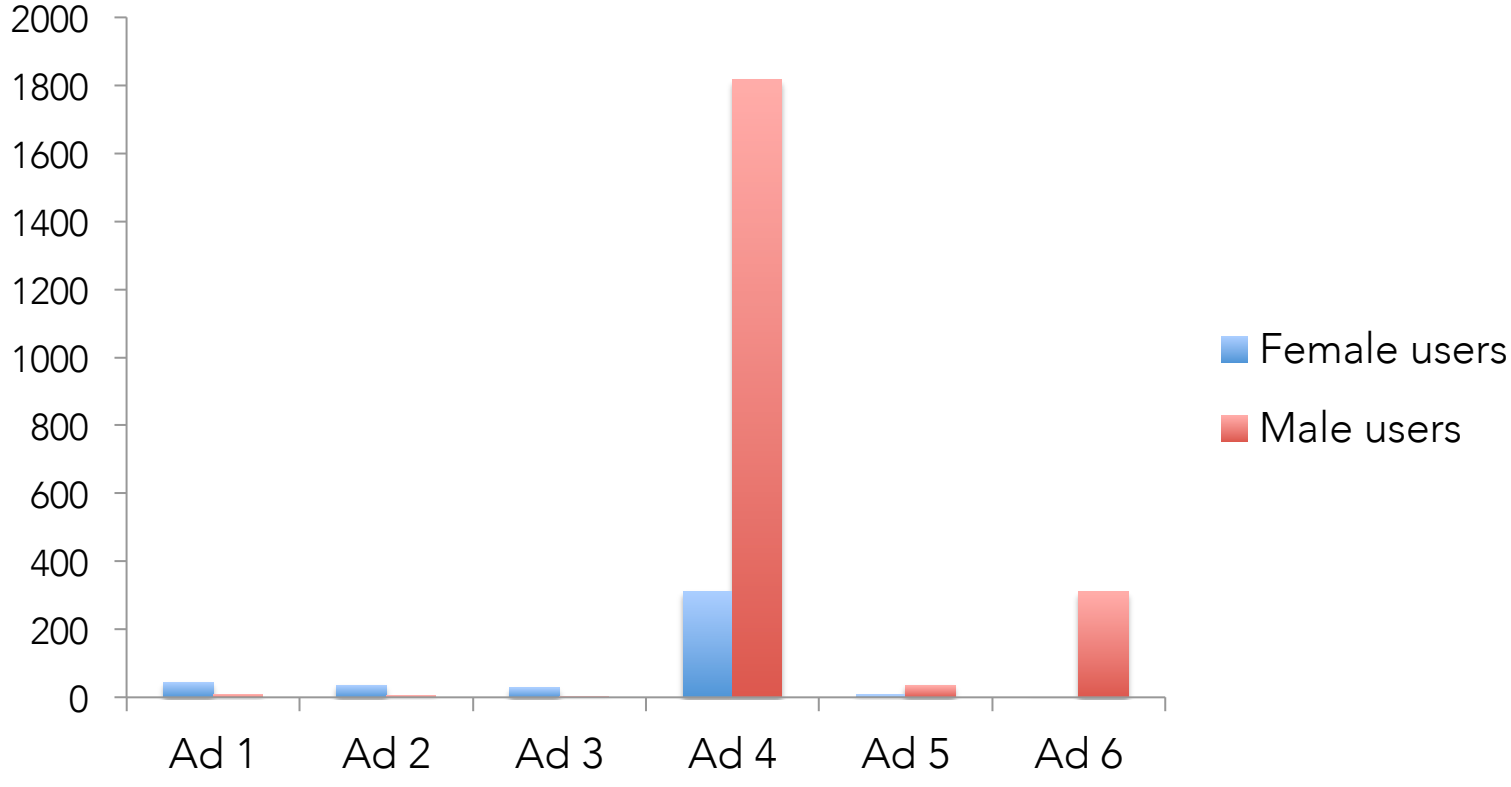
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Ad 1
Ad 2
Ad 3
Ad 4
Ad 5
Ad 6
Female users
Male users

Privacy Policy

www.google.com/policies/privacy/

When showing you tailored ads, we will not associate a cookie or anonymous identifier with sensitive categories, such as those based on **race, religion, sexual orientation or health**.

Choice Explanations

Keeping Dating Interest

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

Top 5 Online Dating Sites
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Why can't I find a date?
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51 vs. 5

Removing 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

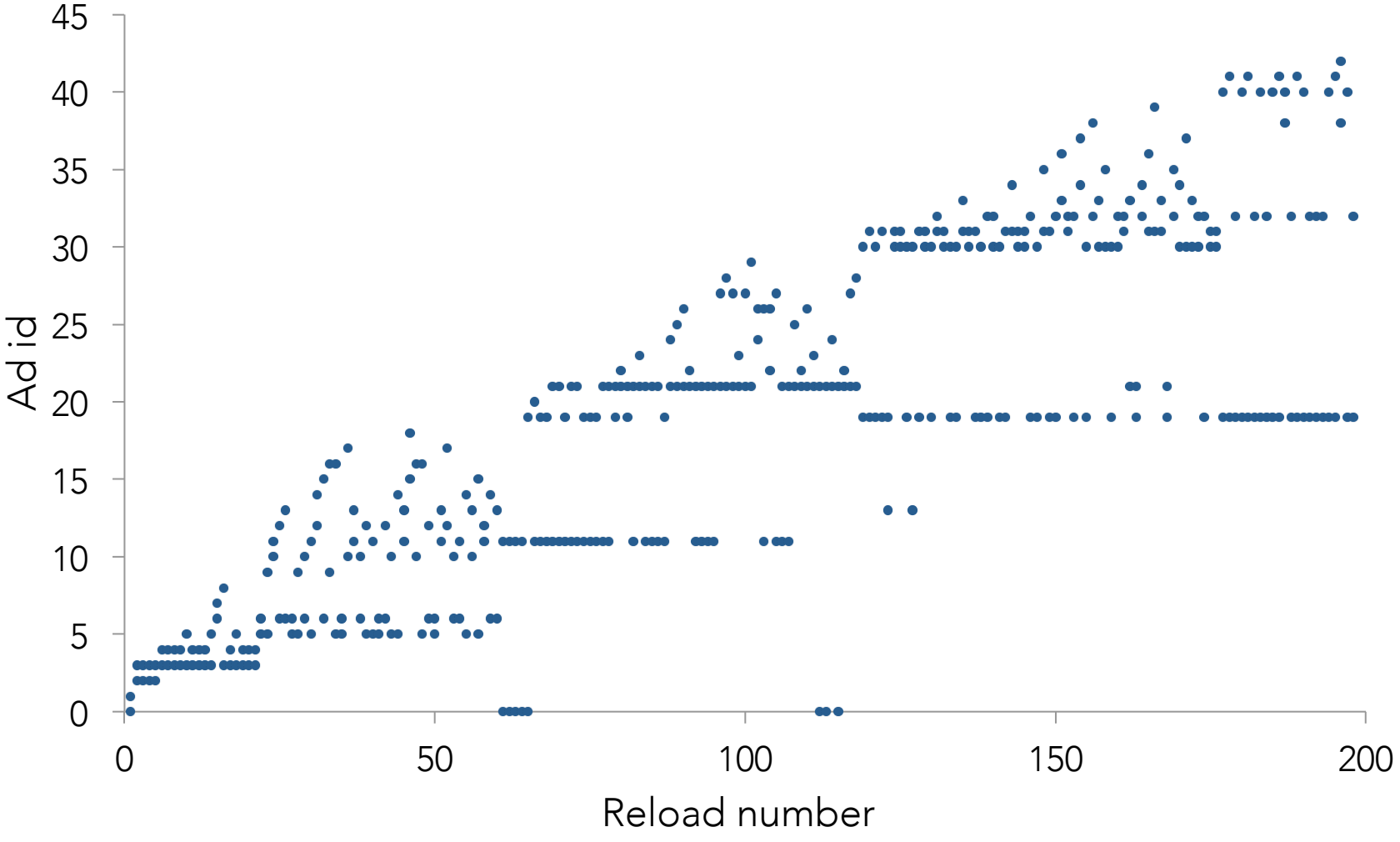
Transparency Explanations

Substance Abuse Visitors	Control Group
The Watershed Rehab www.thewatershed.com/Help 2276 vs. 0	Alluria Alert www.bestbeautybrand.com 0 vs. 9
Watershed Rehab www.thewatershed.com/Rehab 362 vs. 0	Best Dividend Stocks dividends.wyattresearch.com 24 vs. 54
The Watershed Rehab (none) 771 vs. 0	10 Stocks to Hold Forever www.streetauthority.com 76 vs. 118

Findings

- Discrimination
  - Gender affected job-related ads
- Opacity
  - Web browsing affected ads without affecting Ad Settings
- Choice
  - Removing interests affected ads

Mechanism of ad delivery is complex



Prior Work on Behavioral Marketing

Authors	Test	Limitation
Guha et al.	Cosine similarity	No statistical significance
Balebako et al.	Cosine similarity	No statistical significance
Wills and Tatar	Manual examination	No statistical significance
Liu et al. (AdReveal)	Process of elimination	No statistical significance
Barford et al. (AdScape)	χ^2 test	Assumes ads identically distributed
Lécuyer et al. (XRay)	Parametric model	Correlation, not causation; assumes ads are independent
Englehardt et al.	Binomial test	Assumes ads identically

Research Questions

- Are such tools **transparent**?

- Do they provide users with **choice**?

- Can personalized content be **discriminatory**?

Conclusions

- Are ad settings **transparent**?
  No - Web browsing affects ads, not settings

- Do ad settings provide users **choice**?
  Yes - Removing interests affects ads

- Are personalized ads served in a **fair** manner?
  Probably not - Gender affects job-related ads

Privacy Policy

www.google.com/policies/privacy/

When showing you tailored ads, we will not associate a cookie or anonymous identifier with sensitive categories, such as those based on **race, religion, sexual orientation or health**.

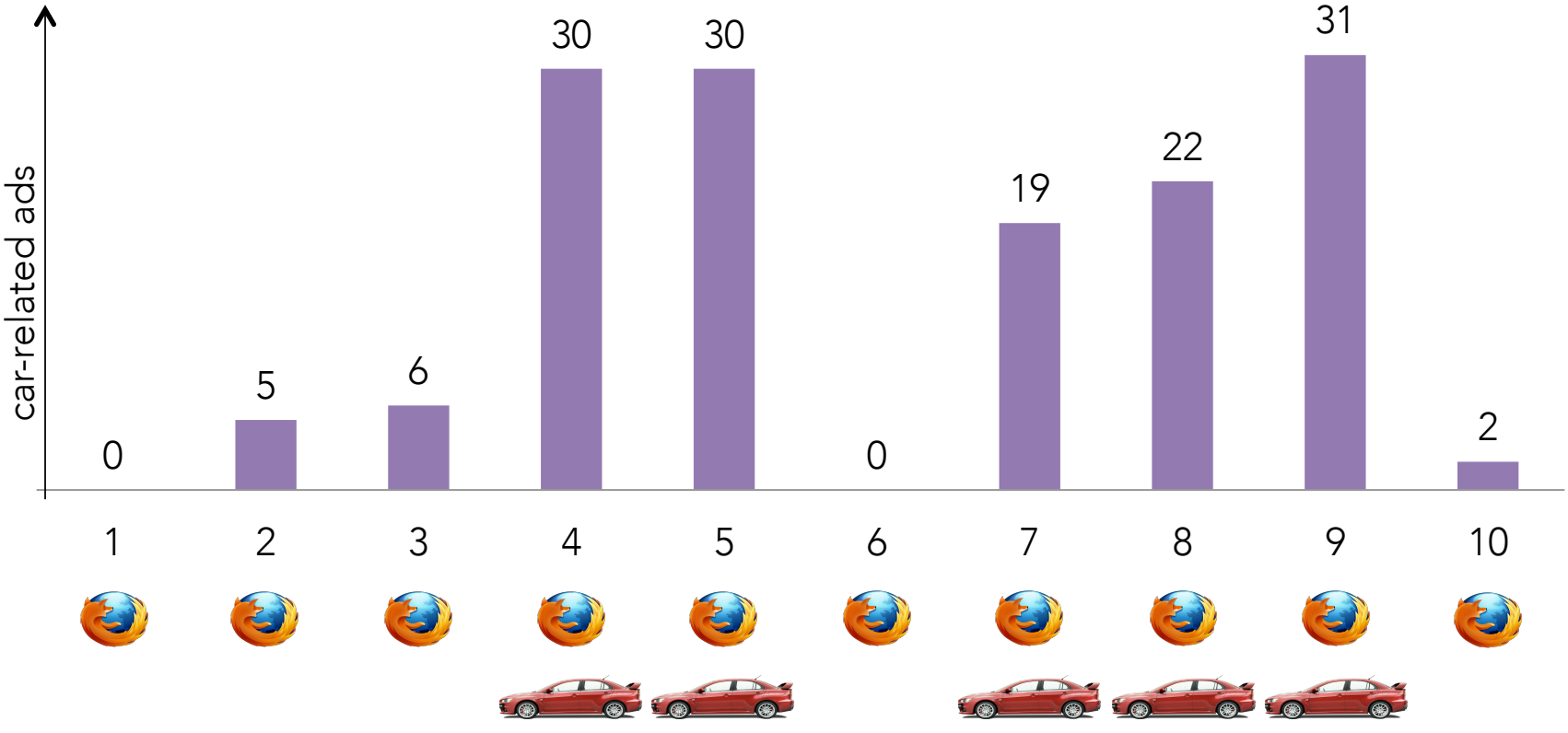
Permutation Test [Good'05]

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

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

P. Good.
Permutation Tests: A Practical Guide to Resampling Methods for Testing Hypotheses. Springer, 2005

Permutation Test: Example



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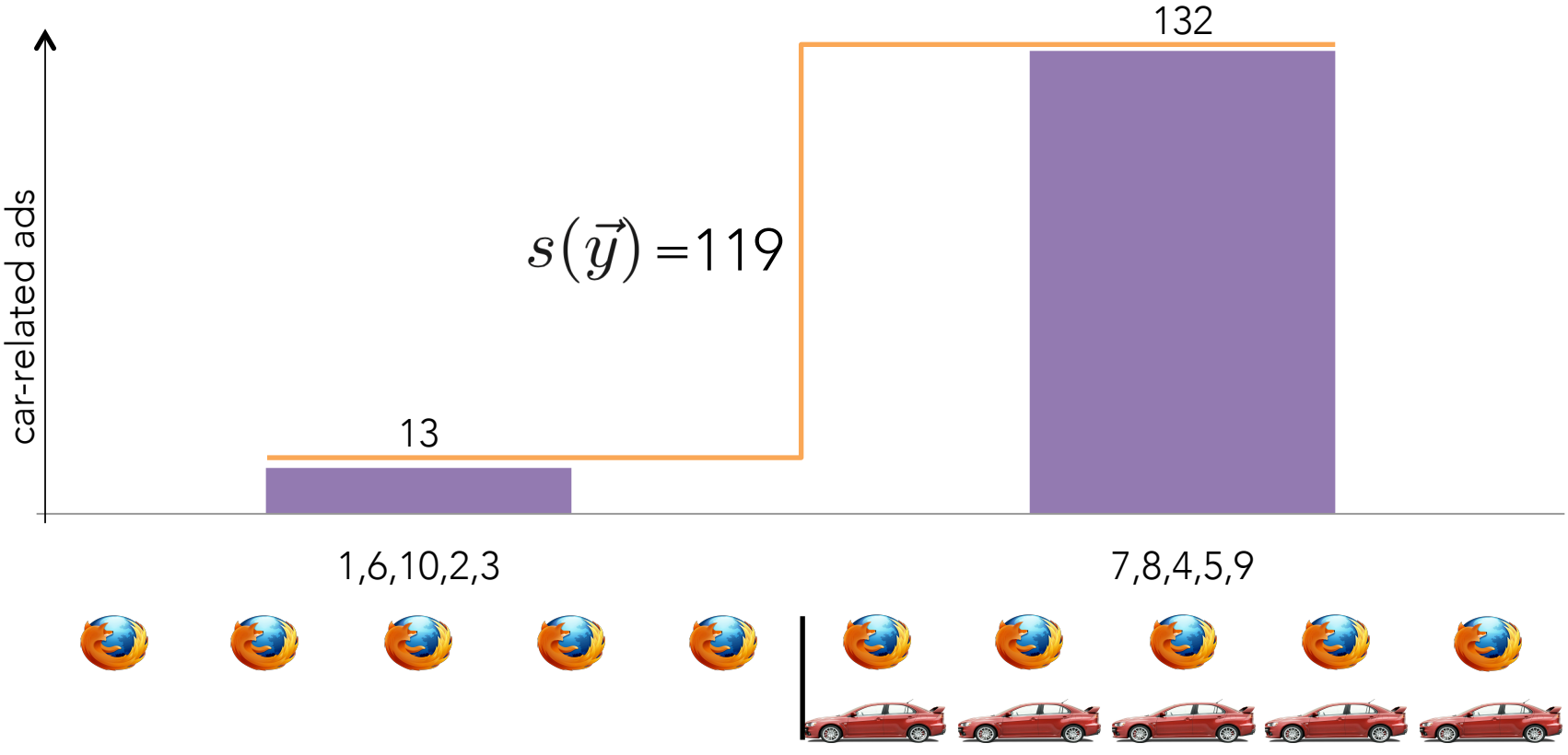

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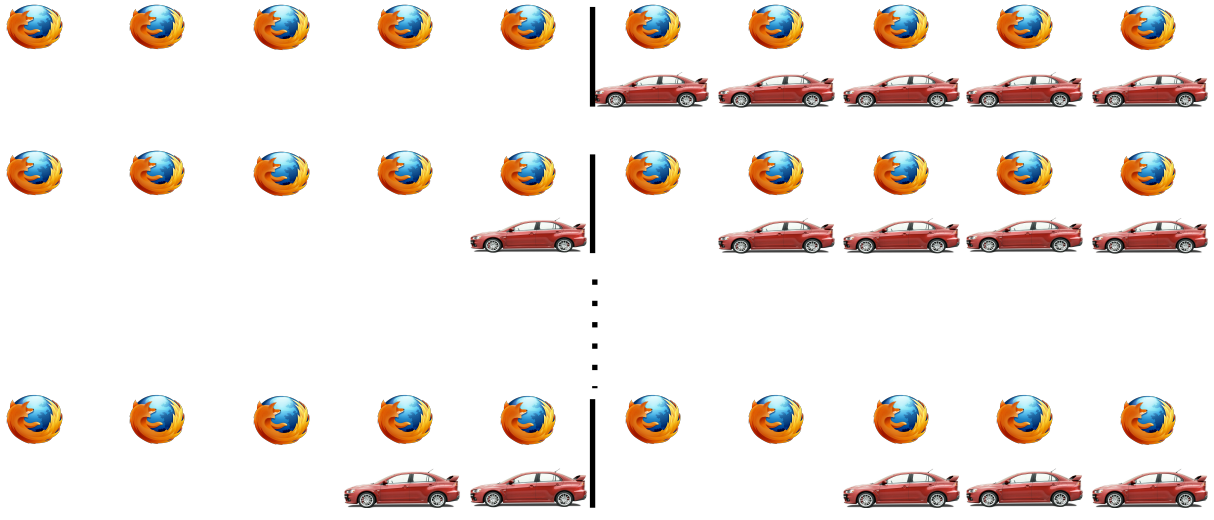

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$s(\pi(\vec{y}))$ =7

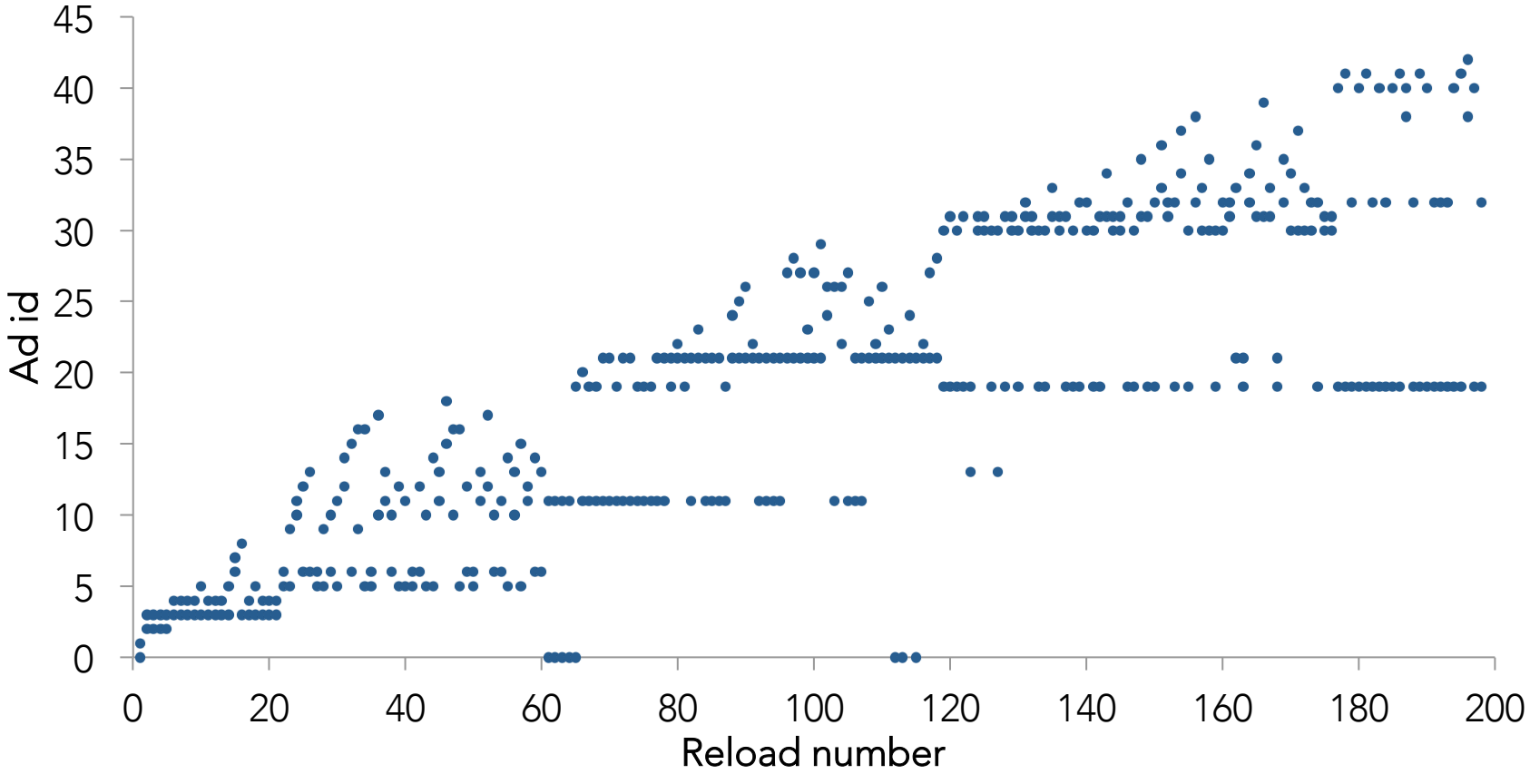
$s(\vec{y})$ = 119

$$\text{p-value} = \frac{\text{count}\left[s(\vec{y}) \leq s(\pi(\vec{y}))\right]}{\text{number of permutations}} = \frac{1}{{}^{10}C_5} = 0.004$$

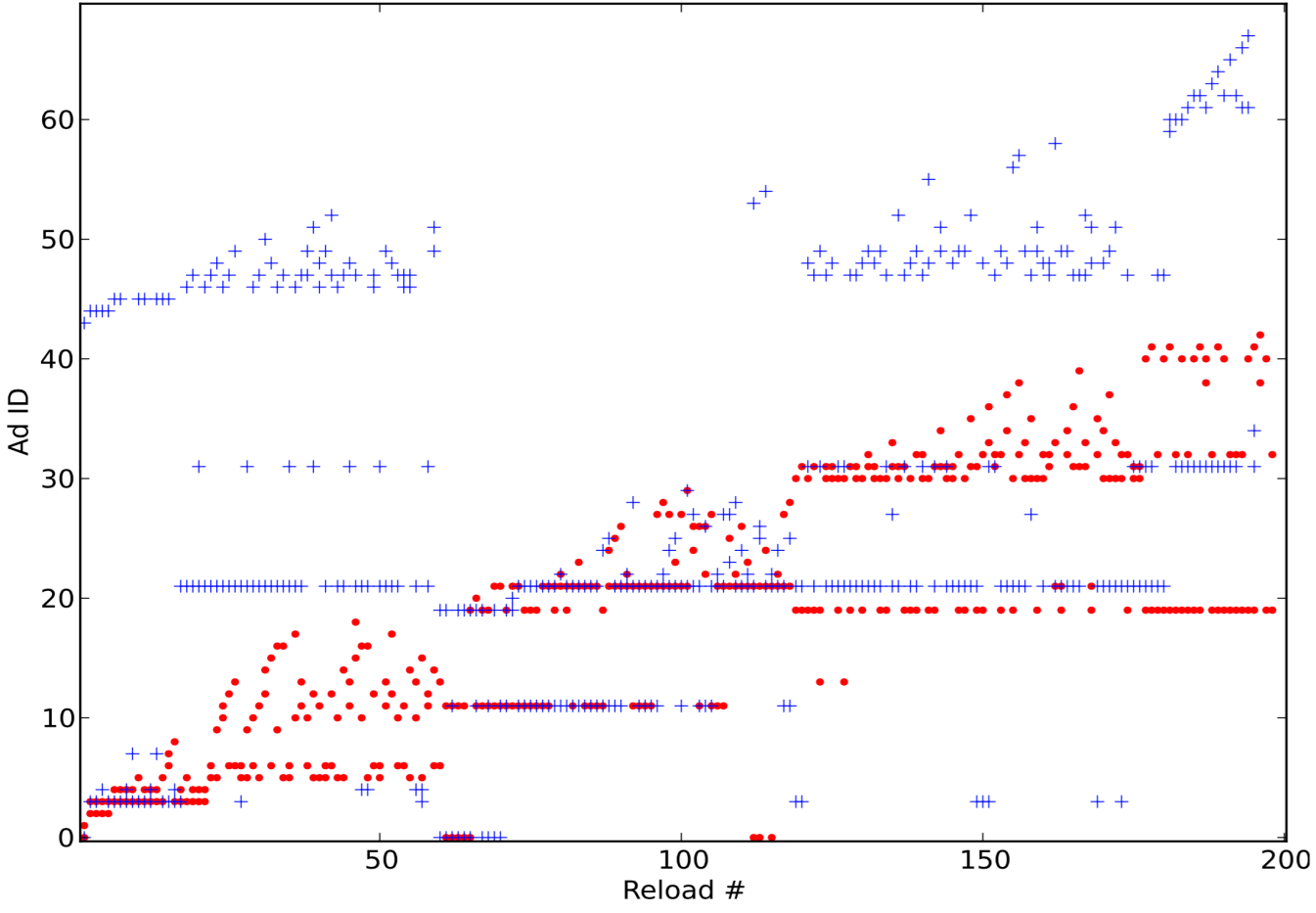
Reject null hypothesis

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

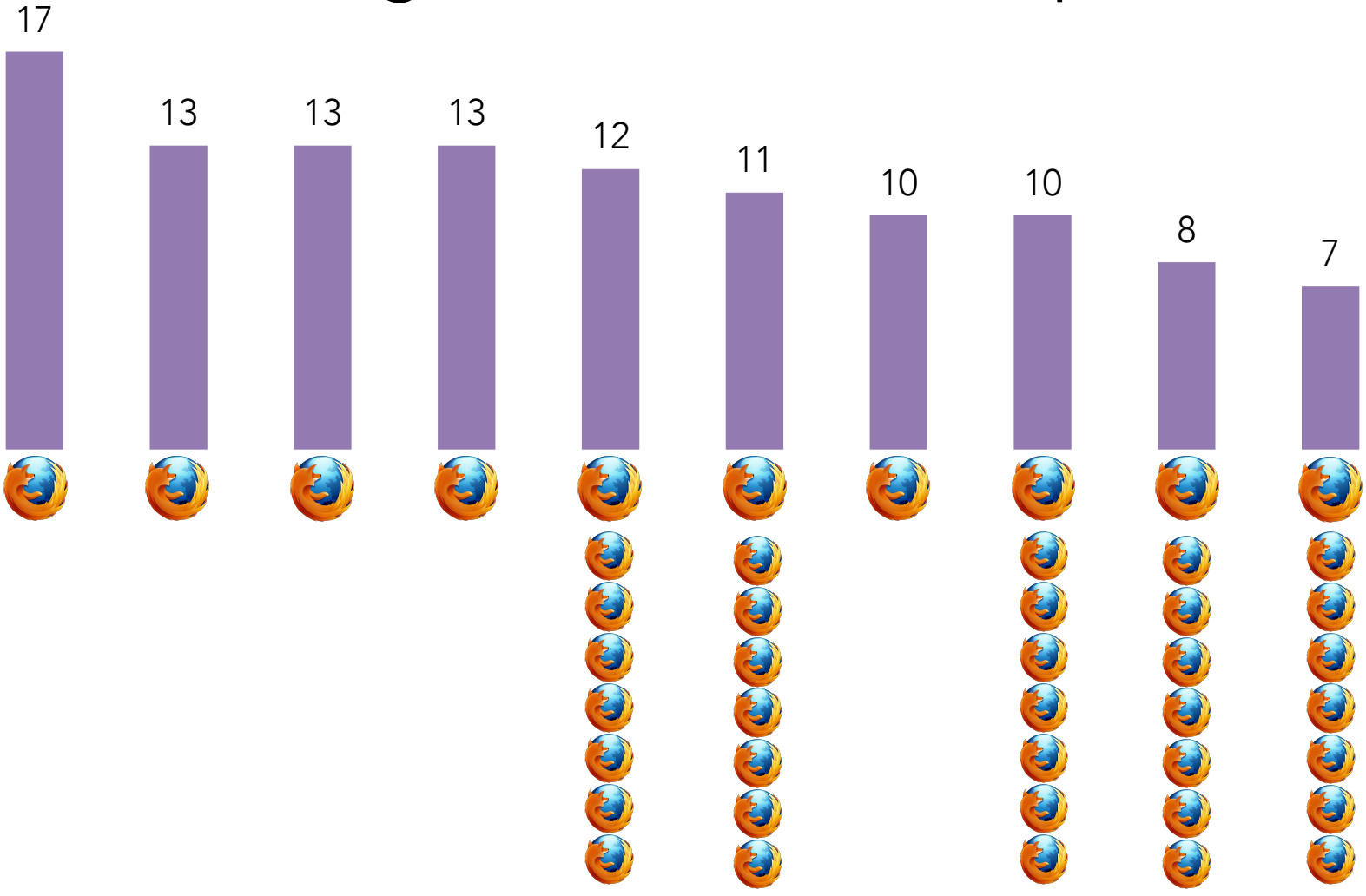
Ads vary over time



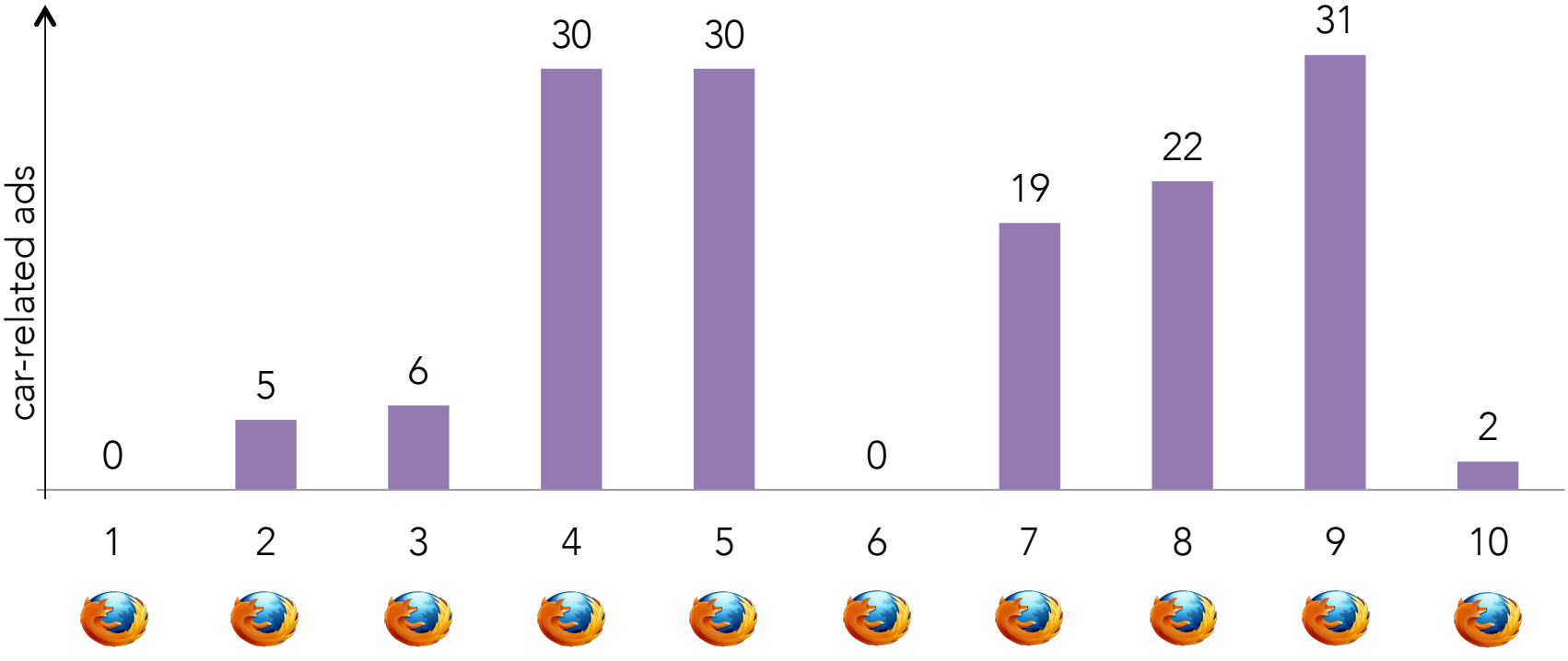
Ads differ on browsers on the same machine at the same time



Browser Agents are not Independent



Permutation Test: Example



"BMW buy", "Audi purchase", "new cars", "local car dealers", "autos and vehicles", "cadillac prices", and "best limousines"

'bmw', 'audi', 'car', 'vehicle', 'automobile', 'cadillac', 'limo'

P value

- Probability of obtaining a result at least as extreme as the one observed, assuming that the null hypothesis is true

- p-value = $\frac{1}{|\vec{y}|!} \sum_{\pi \in \Pi(|\vec{y}|)} I[s(\vec{y}) \leq s(\pi(\vec{y}))]$

I is the indicator function

$s(\vec{y})$ is the statistic computed over $\vec{y}$

$\vec{y}$ is the measurement vector

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

$$p_{ub} = 1 - \text{BetaInv}\left(\frac{\alpha}{2}, n-k, k+1\right)$$

$$p_{lb} = 1 - \text{BetaInv}\left(1-\frac{\alpha}{2}, n-k+1, k\right)$$

Probabilistic Noninterference and Causal Effect

Definition 2 (Probabilistic Noninterference)**.** *A system Q has* probabilistic noninterference *from L to H iff for all input sequences $\vec{i}_1$ and $\vec{i}_2$,*

$$\lfloor \vec{i}_1 \downarrow L \rfloor = \lfloor \vec{i}_2 \downarrow L \rfloor \text{ implies } \lfloor Q(\vec{i}_1) \downarrow L \rfloor = \lfloor Q(\vec{i}_2) \downarrow L \rfloor$$

Definition 3 (Effect)**.** *The experimental factor X has an* effect *on Y given $Z := z$ iff there exists x_1 and x_2 such that the probability distribution of Y in $M[X{:=}x_1][Z{:=}z]$ is not equal to its distribution in $M[X{:=}x_2][Z{:=}z]$.*

Theorem 3. *Q has probabilistic interference iff there exists low inputs ℓ of length t such that $\vec{V}^t_{\mathsf{hi}}$ has an effect on $\vec{V}^t_{\mathsf{lo}}$ given $V^t_{\mathsf{li}} := \ell$.*

Machine Learning Algorithms

Algorithm	Parameter Space	
Logistic Regression	$C = \{2^{-5}, 2^{-4} \ldots, 2^{15}\}$	penalty = $\{L_1, L_2\}$
SVM with poly kernel	$C = \{2^{-5}, 2^{-4} \ldots, 2^{15}\}$	degree = {1, 2, 3, 4}
SVM with RBF kernel	$C = \{2^{-5}, 2^{-4} \ldots, 2^{15}\}$	$\gamma = \{2^{-15}, 2^{-14} \ldots, 2^{3}\}$
k nearest neighbors	k = {1, 3, …, 19}	p = {1, 2, 3}

p in kNN stands for L_p distance

Property	Treatment	Other Actions	Source	When	Length (hrs)	# ads	Result
Nondiscrimination	Gender	-	TOI	May	10	40,400	Inconclusive
	Gender	Jobs	TOI	May	45	43,393	Violation
	Gender	Jobs	TOI	July	39	35,032	Inconclusive
	Gender	Jobs	Guardian	July	53	22,596	Inconclusive
	Gender	Jobs & Top 10	TOI	July	58	28,738	Inconclusive
Data use transparency	Substance abuse	-	TOI	May	37	42,624	Violation
	Substance abuse	-	TOI	July	41	34,408	Violation
	Substance abuse	-	Guardian	July	51	19,848	Violation
	Substance abuse	Top 10	TOI	July	54	32,541	Violation
	Disability	-	TOI	May	44	43,136	Violation
	Mental disorder	-	TOI	May	35	44,560	Inconclusive
	Infertility	-	TOI	May	42	44,982	Inconclusive
	Adult websites	-	TOI	May	57	35,430	Inconclusive
Effectful choice	Opting out	-	TOI	May	9	18,085	Compliance
	Dating interest	-	TOI	May	12	35,737	Compliance
	Dating interest	-	TOI	July	17	22,913	Inconclusive
	Weight loss interest	-	TOI	May	15	31,275	Compliance
	Weight loss interest	-	TOI	July	15	27,238	Inconclusive
Ad choice	Dating interest	-	TOI	July	1	1,946	Compliance
	Weight loss interest	-	TOI	July	1	2,862	Inconclusive
	Weight loss interest	-	TOI	July	1	3,281	Inconclusive

Details of Discrimination Experiments

Treatment	Other visits	Measurement	Blocks	# ads (# unique ads)		Accuracy	Unadj. p-value	Adj. p-value
				female	male			
Gender	Jobs	TOI, May	100	21,766 (545)	21,627 (533)	93%	0.0000053	0.0000265*
Gender	Jobs	Guardian, July	100	11,366 (410)	11,230 (408)	57%	0.12	0.48
Gender	Jobs & Top 10	TOI, July	100	14,507 (461)	14,231 (518)	56%	0.14	n/a
Gender	Jobs	TOI, July	100	17,019 (673)	18,013 (690)	55%	0.20	n/a
Gender	-	TOI, May	100	20,137 (603)	20,263 (630)	48%	0.77	n/a

www.alexa.com/topsites/category/Top/Business/Employment

Details of Discrimination Experiments

Title	URL	Coefficient	appears in agents		total appearances	
			female	male	female	male
Top ads for identifying the simulated female group						
Jobs (Hiring Now)	www.jobsinyourarea.co	0.34	6	3	45	8
4Runner Parts Service	www.westernpatoyotaservice.com	0.281	6	2	36	5
Criminal Justice Program	www3.mc3.edu/Criminal+Justice	0.247	5	1	29	1
Goodwill - Hiring	goodwill.careerboutique.com	0.22	45	15	121	39
UMUC Cyber Training	www.umuc.edu/cybersecuritytraining	0.199	19	17	38	30
Top ads for identifying agents in the simulated male group						
$200k+ Jobs - Execs Only	careerchange.com	−0.704	60	402	311	1816
Find Next $200k+ Job	careerchange.com	−0.262	2	11	7	36
Become a Youth Counselor	www.youthcounseling.degreeleap.com	−0.253	0	45	0	310
CDL-A OTR Trucking Jobs	www.tadrivers.com/OTRJobs	−0.149	0	1	0	8
Free Resume Templates	resume-templates.resume-now.com	−0.149	3	1	8	10

Details of Transparency Experiments

Treatment	Other visits	Measurement	# ads (# unique ads)		Accuracy	Unadj. p-value	Adj. p-value
			experimental	control			
Substance abuse	-	TOI, May	20,420 (427)	22,204 (530)	81%	0.0000053	0.0000424*
Substance abuse	-	TOI, July	16,206 (653)	18,202 (814)	98%	0.0000053	0.0000371*
Substance abuse	Top 10	TOI, July	15,713 (603)	16,828 (679)	65%	0.0000053	0.0000318*
Disability	-	TOI, May	19,787 (546)	23,349 (684)	75%	0.0000053	0.0000265*
Substance abuse	-	Guardian, July	8,359 (242)	11,489 (319)	62%	0.0075	0.03*
Mental disorder	-	TOI, May	22,303 (407)	22,257 (465)	59%	0.053	0.159
Infertility	-	TOI, May	22,438 (605)	22,544 (625)	57%	0.11	n/a
Adult websites	-	TOI, May	17,670 (602)	17,760 (580)	52%	0.42	n/a

www.alexa.com/topsites/category/Top/Health/Addictions/Substance_Abuse
www.alexa.com/topsites/category/Top/Society/Disabled

Details of Transparency Experiments

Title	URL	Coefficient	appears in agents		total appearances	
			control	experi.	control	experi.
Top ads for identifying agents in the experimental group (visited websites associated with substance abuse)						
The Watershed Rehab	www.thewatershed.com/Help	−0.888	0	280	0	2276
Watershed Rehab	www.thewatershed.com/Rehab	−0.670	0	51	0	362
The Watershed Rehab	Ads by Google	−0.463	0	258	0	771
Veteran Home Loans	www.vamortgagecenter.com	−0.414	13	15	22	33
CAD Paper Rolls	paper-roll.net/Cad-Paper	−0.405	0	4	0	21
Top ads for identifying agents in control group						
Alluria Alert	www.bestbeautybrand.com	0.489	2	0	9	0
Best Dividend Stocks	dividends.wyattresearch.com	0.431	20	10	54	24
10 Stocks to Hold Forever	www.streetauthority.com	0.428	51	44	118	76
Delivery Drivers Wanted	get.lyft.com/drive	0.362	22	6	54	14
VA Home Loans Start Here	www.vamortgagecenter.com	0.354	23	6	41	9

Details of Choice Experiment

Experiment	blocks	# ads (# unique ads)			accuracy	Unadj. p-value	Adj. p-value
		removed/opt-out	keep/opt-in	total			
Opting out	54	9,029 (139)	9,056 (293)	18,085 (366)	83%	0.0000053	0.0000265*
Dating (May)	100	17,975 (518)	17,762 (457)	35,737 (669)	74%	0.0000053	0.0000212*
Weight Loss (May)	83	15,826 (367)	15,449 (427)	31,275 (548)	60%	0.041	0.123
Dating (July)	90	11,657 (727)	11,256 (706)	22,913 (1,014)	59%	0.070	n/a
Weight Loss (July)	100	14,168 (917)	13,070 (919)	27,238 (1,323)	52%	0.41	n/a

Details of Choice Experiment

Title	URL	Coefficient	appears in agents		total appearances	
			kept	removed	kept	removed
Top ads for identifying the group that kept dating interests						
Are You Single?	www.zoosk.com/Dating	1.583	367	33	2433	78
Top 5 Online Dating Sites	www.consumer-rankings.com/Dating	1.109	116	10	408	13
Why can't I find a date?	www.gk2gk.com	0.935	18	3	51	5
Latest Breaking News	www.onlineinsider.com	0.624	2	1	6	1
Gorgeous Russian Ladies	anastasiadate.com	0.620	11	0	21	0
Top ads for identifying agents in the group that removed dating interests						
Car Loans w/ Bad Credit	www.car.com/Bad-Credit-Car-Loan	−1.113	5	13	8	37
Individual Health Plans	www.individualhealthquotes.com	−0.831	7	9	21	46
Crazy New Obama Tax	www.endofamerica.com	−0.722	19	31	22	51
Atrial Fibrillation Guide	www.johnshopkinshealthalerts.com	−0.641	0	6	0	25
Free $5 - $25 Gift Cards	swagbucks.com	−0.614	4	11	5	32

Details of Choice Experiment

Experiment	Keywords	# ads (# unique ads)		appearances	
		removed	kept	removed	kept
Dating	dating, romance, relationship	952 (117)	994 (123)	34	109
Weight Loss (1)	fitness	1,461 (259)	1,401 (240)	21	16
Weight Loss (2)	fitness, health, fat, diet, exercise	1,803 (199)	1,478 (192)	2	15

Experiment	Unadjusted p-value	Bonferroni p-value	Holm-Bonferroni p-value	Unadjusted flipped p-value	Bonferroni flipped p-value	Holm-Bonferroni flipped p-value
Dating	0.0076	0.0152	0.0456*	0.9970	1.994	n/a
Weight Loss (2)	0.18	0.36	0.9	0.9371	1.8742	n/a
Weight Loss (1)	0.72	1.44	n/a	0.3818	0.7636	n/a