

18734: Foundations of Privacy

Information Flow Experiments

Anupam Datta

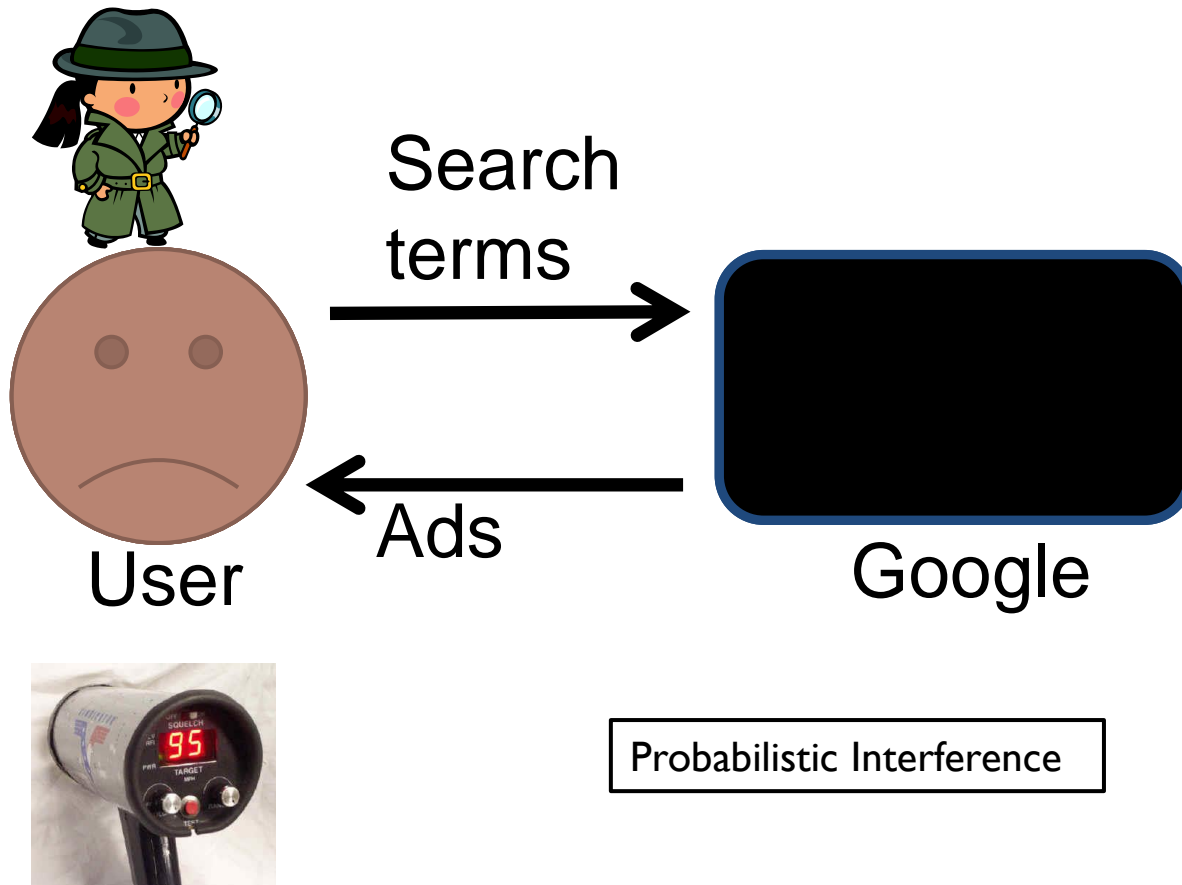
Fall 2014

Information Flow Experiments

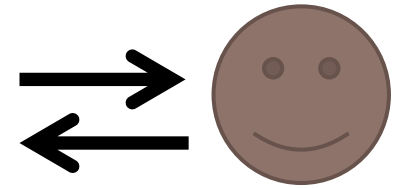
Methodology

With Michael Carl Tschantz (CMU → UC Berkeley)
Amit Datta (CMU)
Jeannette M. Wing (CMU → Microsoft Research)

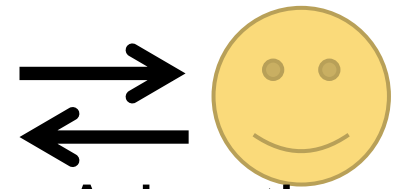
Personalized Web Advertising



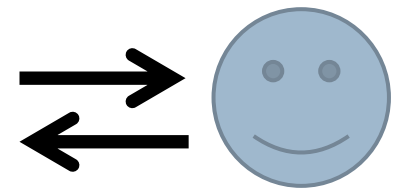
Confounding inputs



Other users



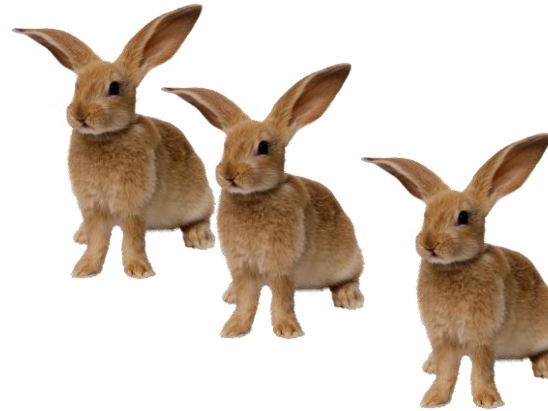
Advertisers



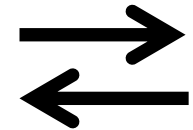
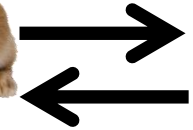
Websites

Experimental Design

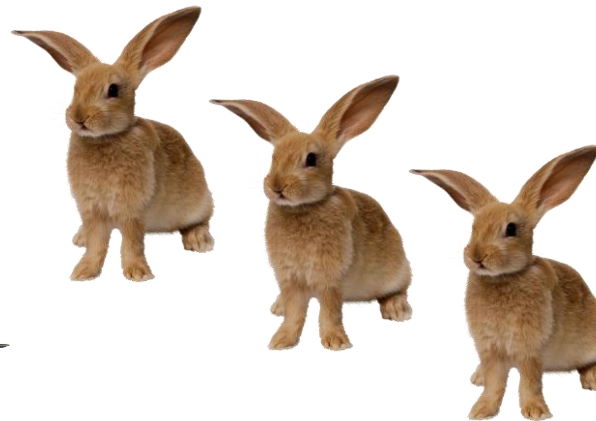
Drug



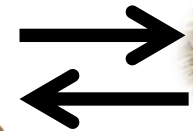
Experimental Group



Placebo

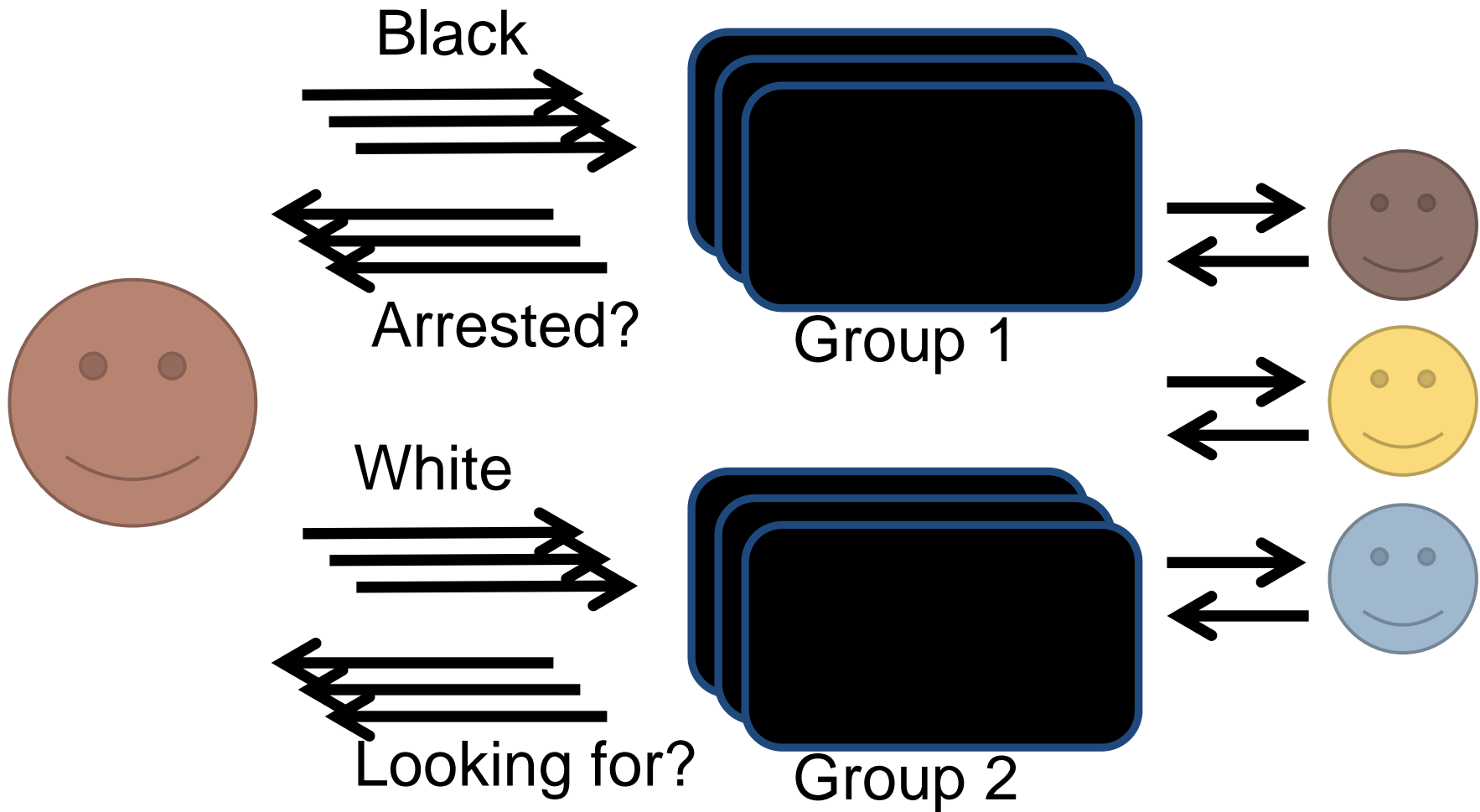


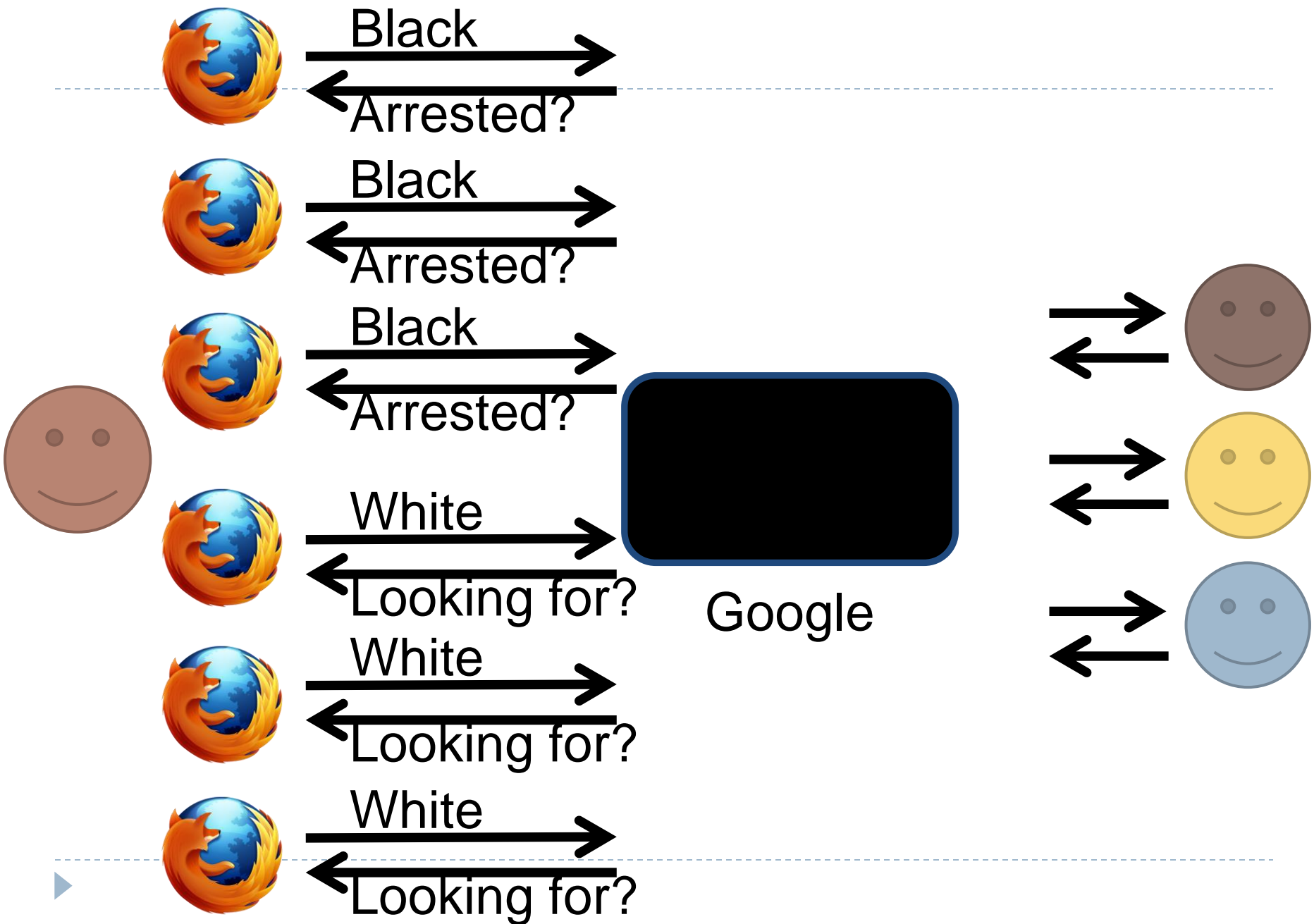
Control Group



Scientist

Information Flow Experiment





Information Flow Experiments as Science

Experimental Science

Information Flow

Natural process

System in question

Population of units

Subset of interactions

...

...

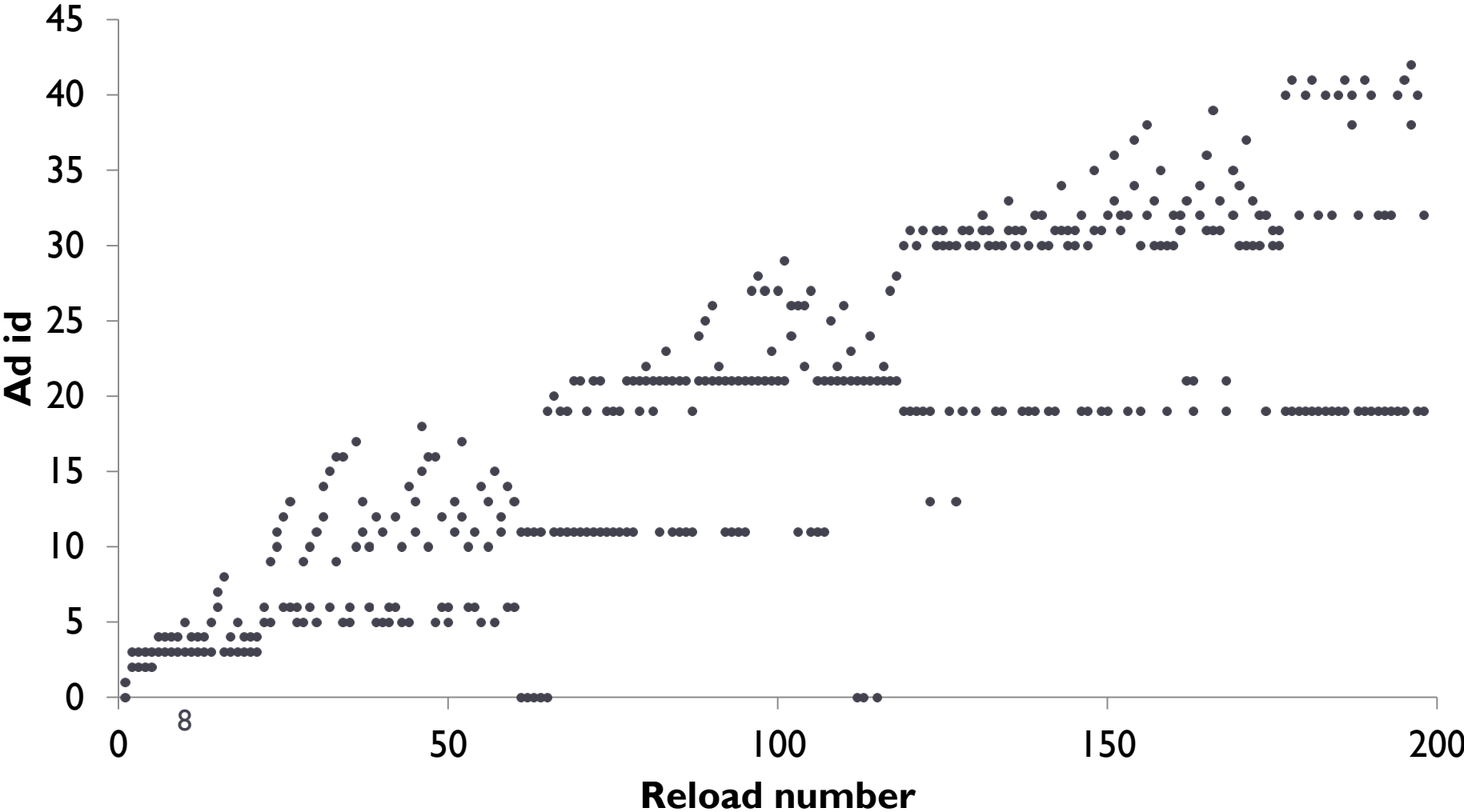
Causation

Information flow

Pearl's Causation = Probabilistic Interference

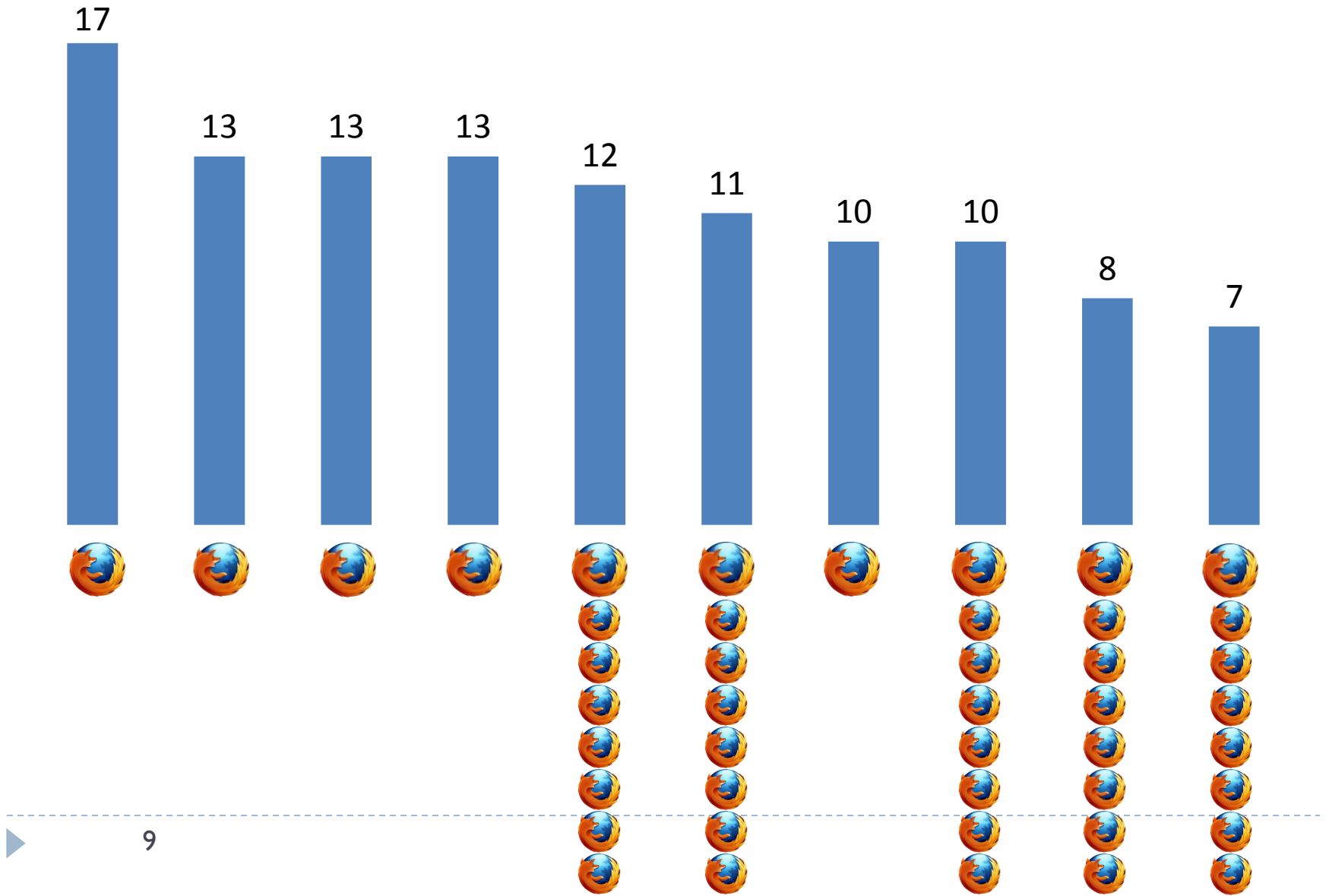
Theorem

Google Exhibits Complex Behavior



8

Browser Instances are Not Independent

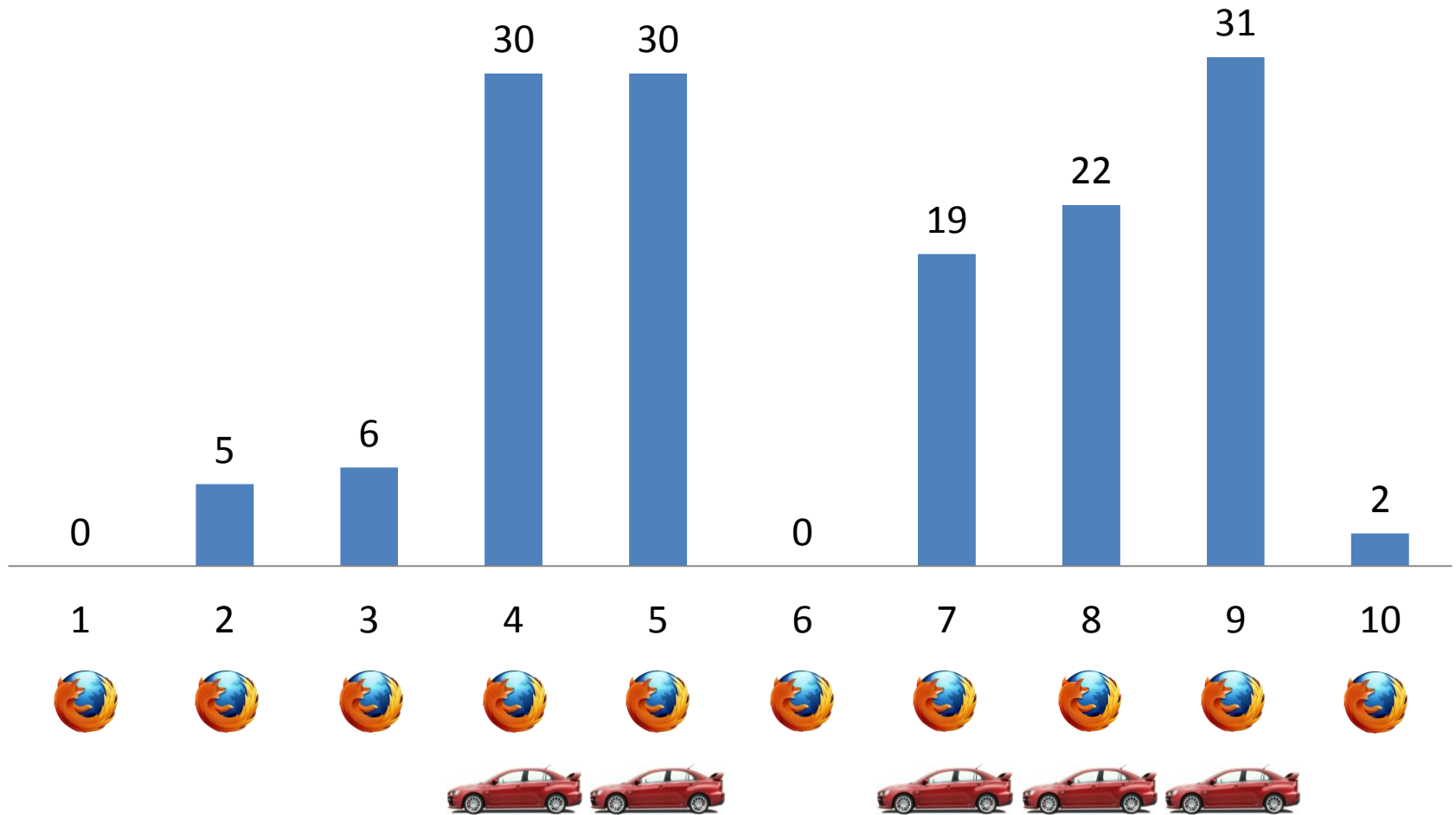


Which Statistical Test to Use?

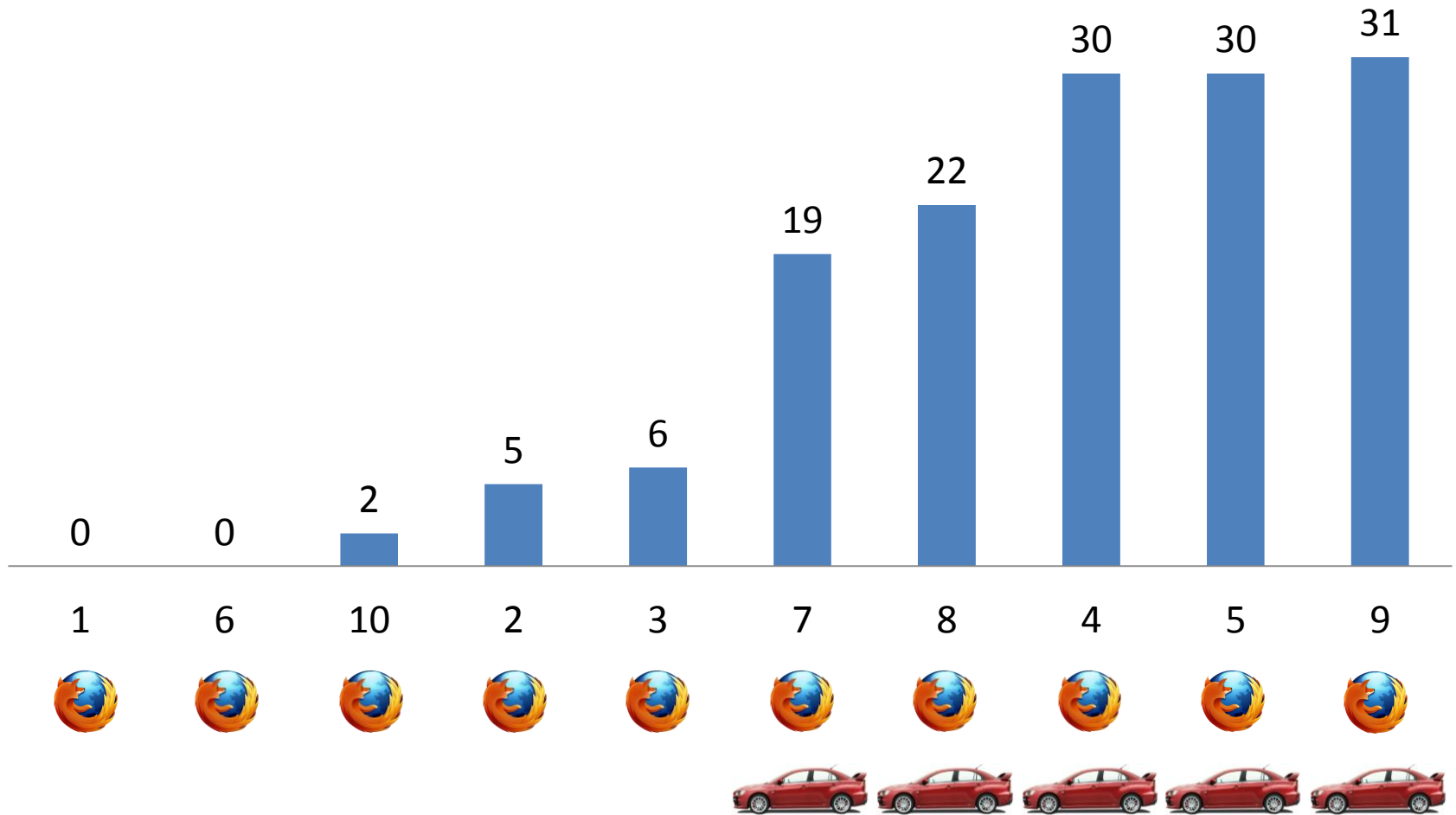
Our Idea:

- ▶ Use a non-parametric test
 - ▶ Does not require model of Google
- ▶ Specifically, a permutation test
 - ▶ Does not require independence among browser instances or assumption that ads are independent and identically distributed

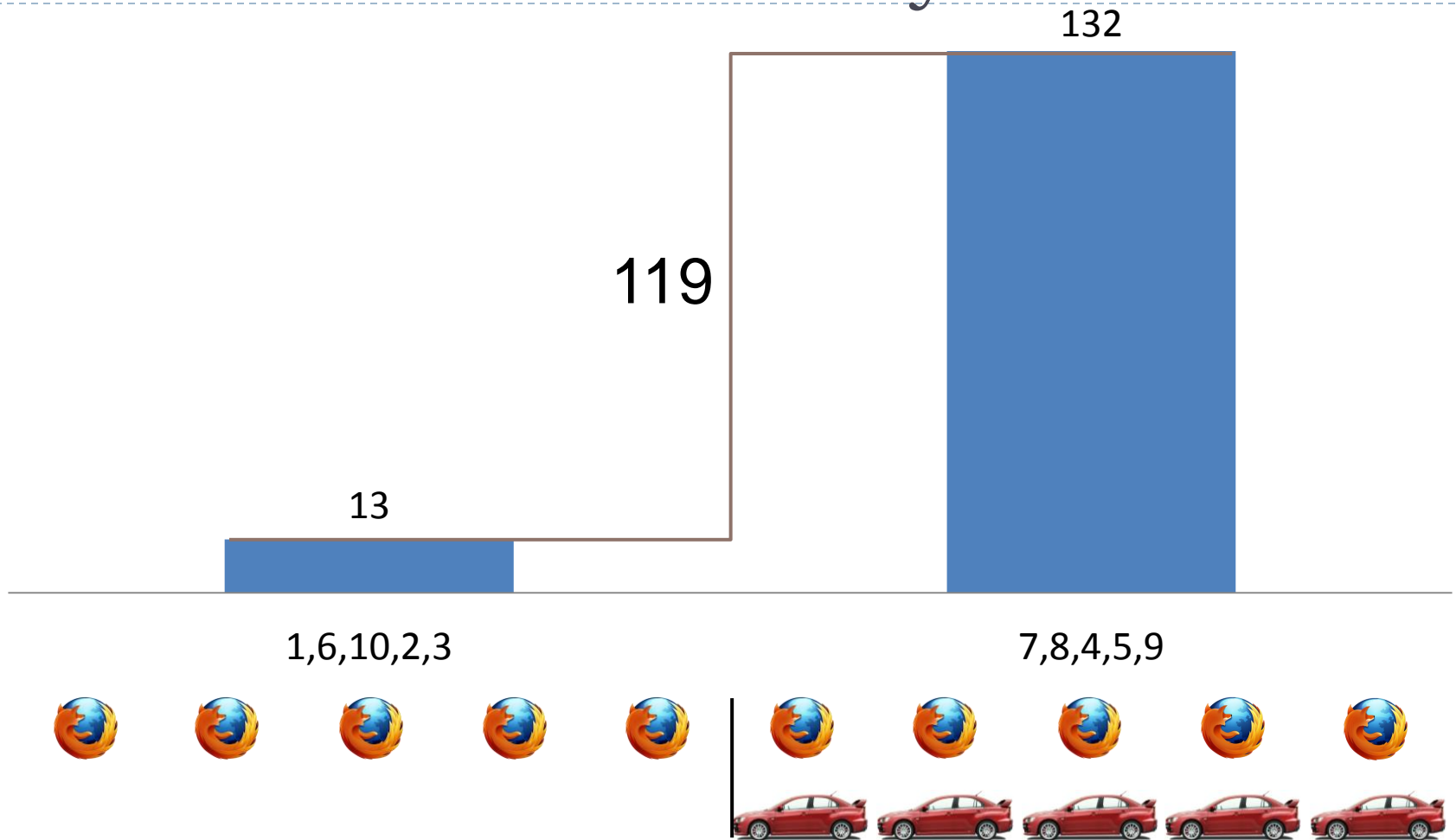
Permutation Test over Keywords



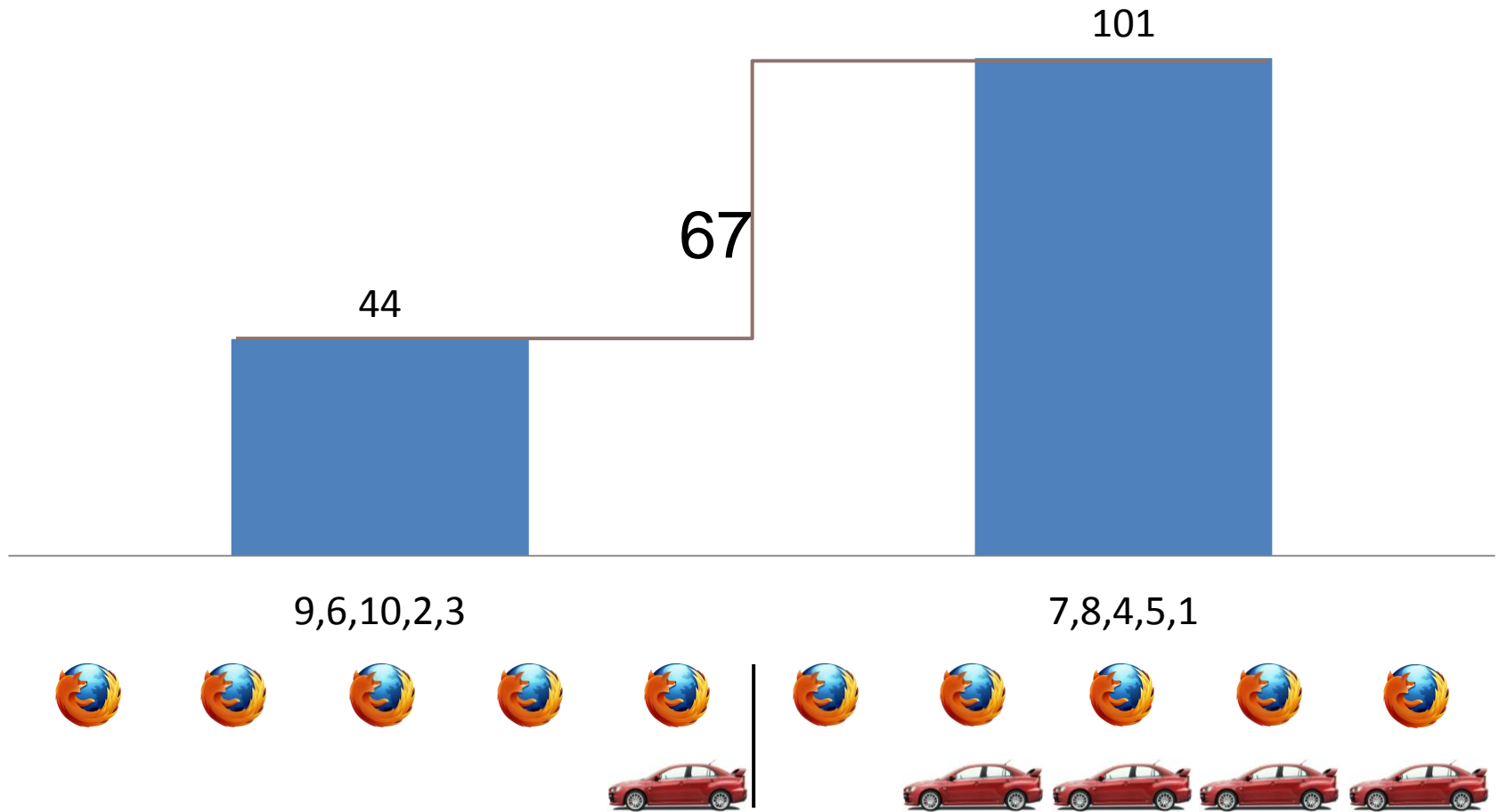
Permutation Test over Keywords



Permutation Test over Keywords



Permutation Test over Keywords



Permutation Test over Keywords



Conclusion

- ▶ A rigorous methodology for information flow experiments
 1. Probabilistic interference = Pearl's causation
 2. Experimental design for causal determination
 3. Significance testing with non-parametric statistics

Information Flow Experiments
on Personalized Ad Settings:
A Tale of Opacity, Choice and Discrimination

With Amit Datta (CMU) and
Michael Carl Tschantz (UC Berkeley)



Google Ad Settings

Settings for Google ads

Ads enable free web services and content. These settings help control the types of Google ads you see.

Ads on Google



Search

Google ads across the web ?



Google ads across the web



YouTube

Gender

N/A

Female [Edit](#)

Based on the websites you've visited

Age

N/A

25-34 [Edit](#)

Based on the websites you've visited

Languages

N/A

English [Edit](#)

Based on the websites you've visited

Interests

N/A

Adoption, and 244 more [Edit](#)

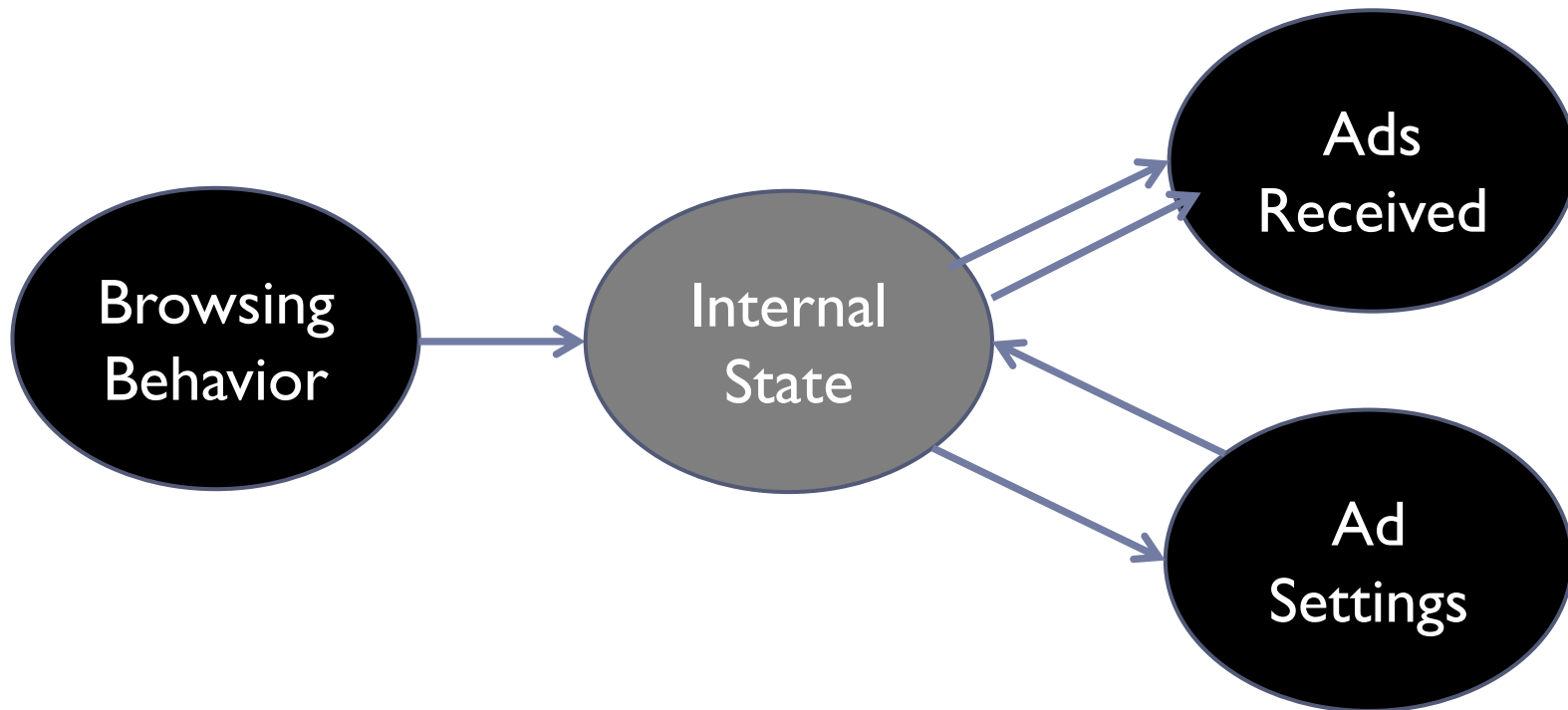
Based on the websites you've visited

Opt-out settings

[Opt out of interest-based ads on Google](#)

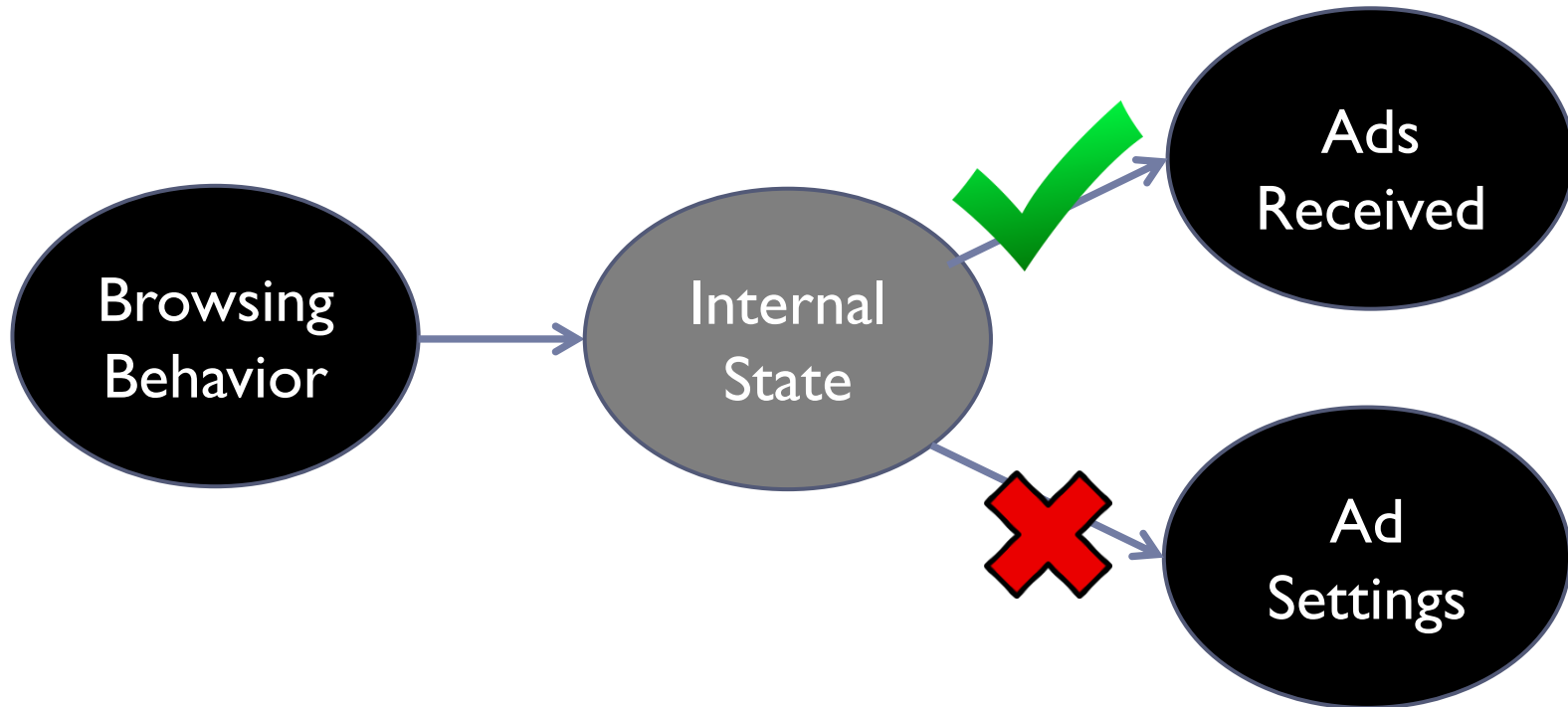
[Opt out of interest-based Google ads across the web](#)

Goals



- ▶ Study *transparency, choice, fairness*
- ▶ Methodology and tool (AdFisher)
 - ▶ Automation, statistical rigor, scalability, explanations

Experiment 1: Opacity



- ▶ Experimental group visits top 100 substance abuse sites
- ▶ Control group idles
- ▶ Then both groups visit Times of India and collect ads

Experiment 1: Significant Opacity

Treatment	p-value
Substance abuse	0.0000053
Disability	0.0000053
Mental disorder	0.053
Infertility	0.11
Adult websites	0.42

Statistical
significance

- ▶ Substance abuse: significant effect on ads, **no effect** on ad settings
- ▶ Disability: significant effect on ads, **“unrelated” effect** on ad settings

Experiment 1: Opacity Explanation

Top ads for group visiting substance abuse webpages

The Watershed Rehab

www.thewatershed.com/Help

Watershed Rehab

www.thewatershed.com/Rehab

The Watershed Rehab

Ads by Google

The Watershed Rehab

www.thewatershed.com/Help - Drug & Alcohol Rehabilitation Call Today For Help Now!

Ads by Google

Top ads for control group

Alluria Alert

www.bestbeautybrand.com

Best Dividend Stocks

dividends.wyattresearch.com

10 Stocks to Hold Forever

www.streetauthority.com

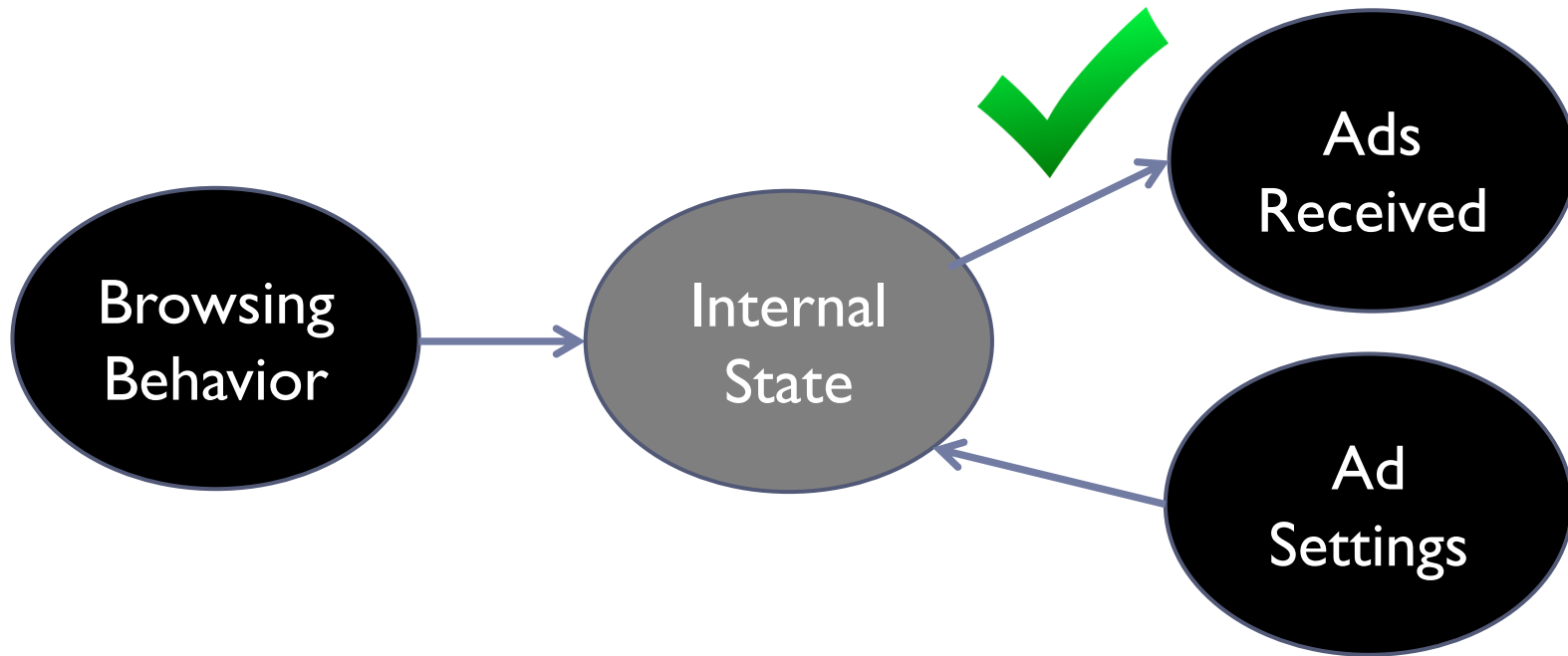
Delivery Drivers Wanted

get.lyft.com/drive

VA Home Loans Start Here

www.vamortgagecenter.com

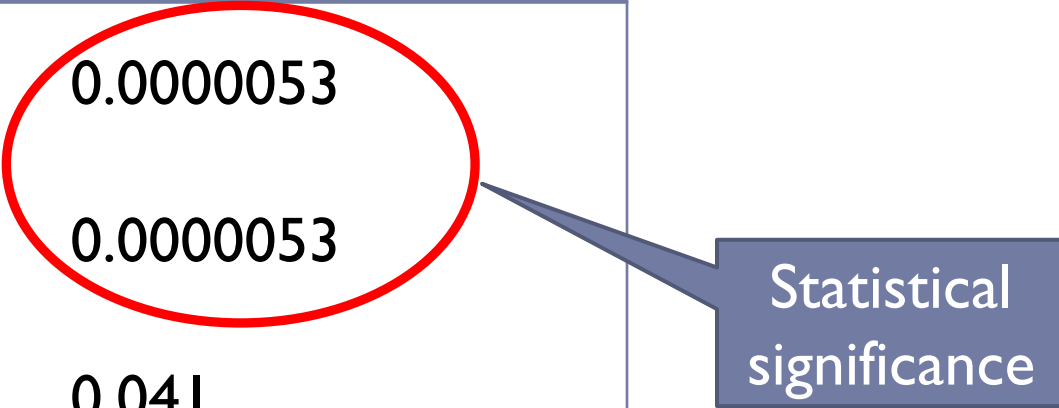
Experiment 2: Choice



- ▶ Experimental group visits top 100 dating sites; then removes dating interest from ad settings
- ▶ Control group visits top 100 dating sites; then keeps dating interest
- ▶ Then both groups visit Times of India and collect ads

Experiment 2: Choice Buttons have an Effect

Treatment	p-value
Opting out	0.0000053
Dating	0.0000053
Weight loss	0.041



Statistical significance

Experiment 2: Choice Explanation

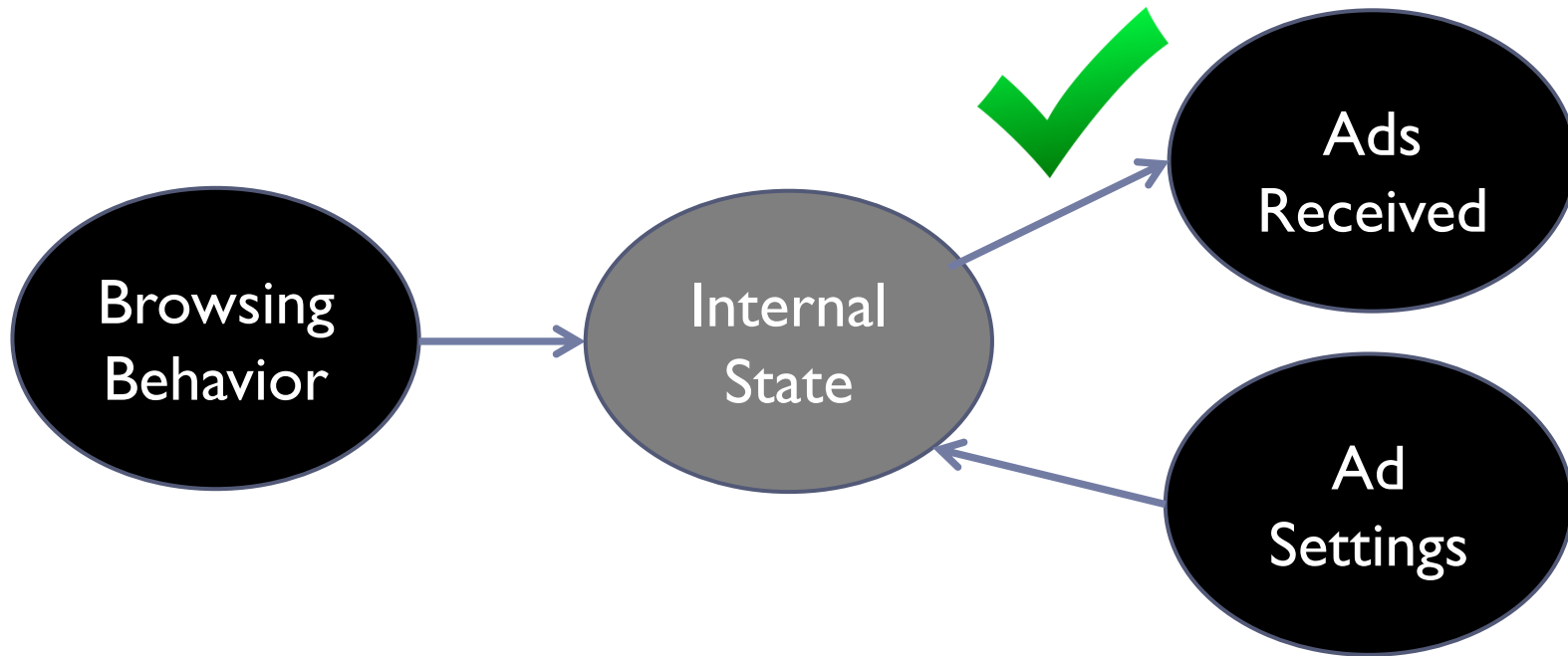
Top ads for group keeping dating interest

Are You Single?	www.zoosk.com/Dating
Top 5 Online Dating Sites	www.consumer-rankings.com/Dating
Why can't I find a date?	www.gk2gk.com
Latest Breaking News	www.onlineinsider.com
Gorgeous Russian Ladies	anastasiadate.com

Top ads for group removing dating interest

Car Loans w/ Bad Credit	www.car.com/Bad-Credit-Car-Loan
Individual Health Plans	www.individualhealthquotes.com
Crazy New Obama Tax	www.endofamerica.com
Atrial Fibrillation Guide	www.johnshopkinshealthalerts.com
Free \$5 - \$25 Gift Cards	swagbucks.com

Experiment 3: Discrimination



- ▶ Experimental group visits top 100 job sites with gender set to male in ad settings
- ▶ Control group visits top 100 job sites with gender set to female in ad settings
- ▶ Then both groups visit Times of India and collect ads

Experiment 3: Discrimination Explanation

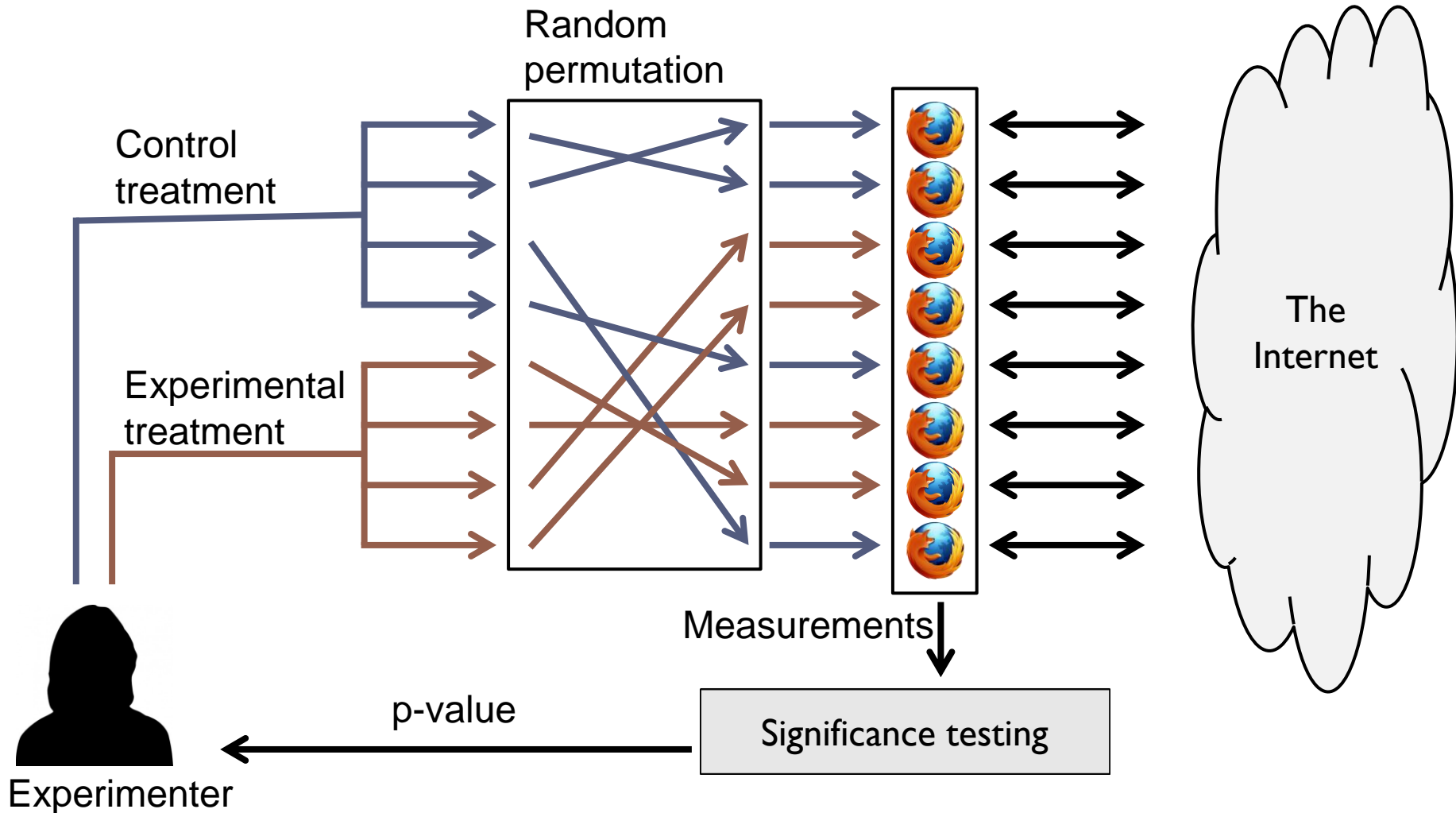
Top ads for female group

Jobs (Hiring Now)	www.jobsinyourarea.co
4Runner Parts Service	www.westernpatoyotaservice.com
Criminal Justice Program	www3.mc3.edu/Criminal+Justice
Goodwill - Hiring	goodwill.careerboutique.com
UMUC Cyber Training	www.umuc.edu/cybersecuritytraining

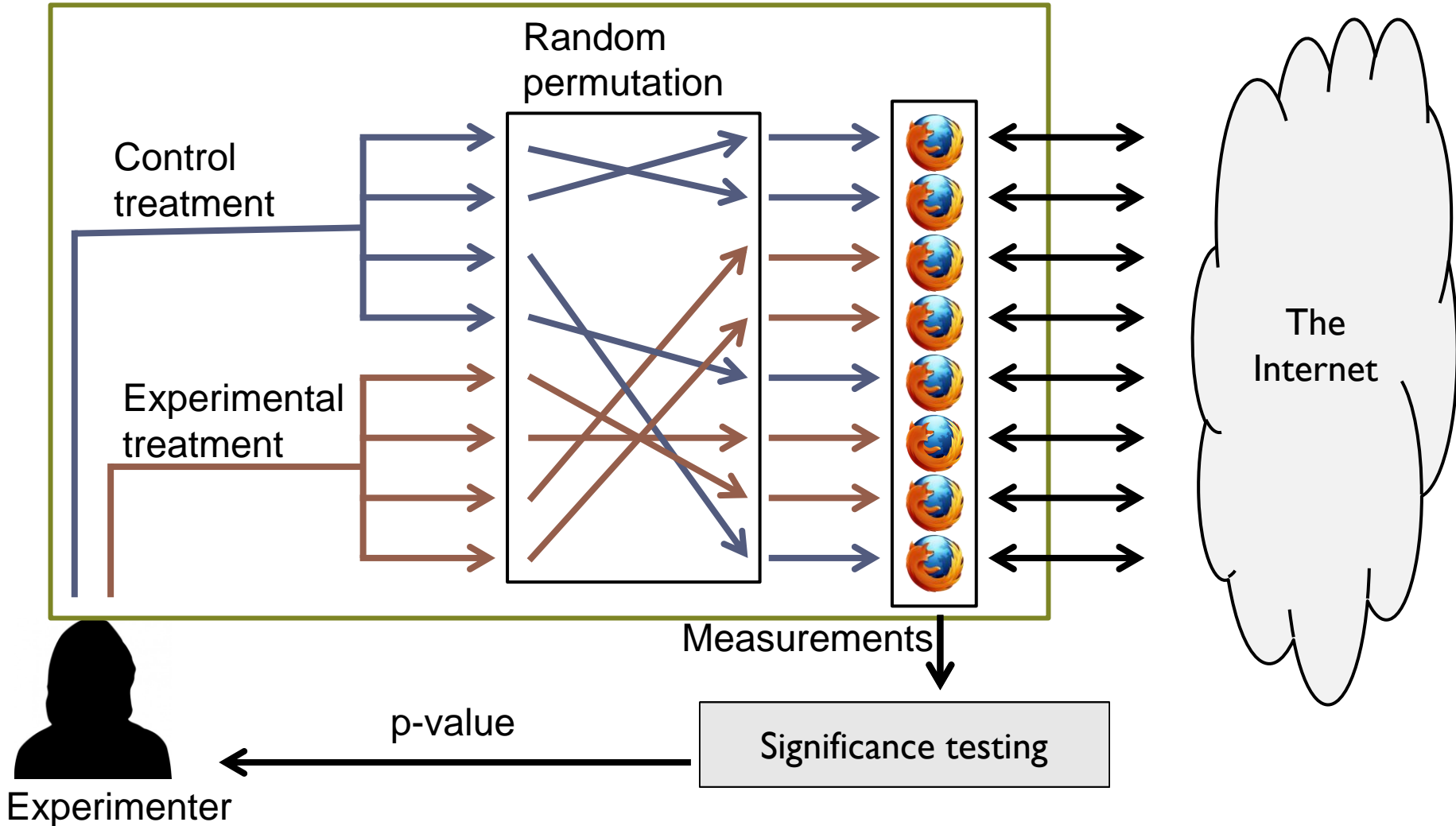
Top ads for male group

\$200k+ Jobs - Execs Only	careerchange.com
Find Next \$200k+ Job	careerchange.com
Become a Youth Counselor	www.youthcounseling.degreeleap.com
CDL-A OTR Trucking Jobs	www.tadrivers.com/OTRJobs
Free Resume Templates	resume-templates.resume-now.com

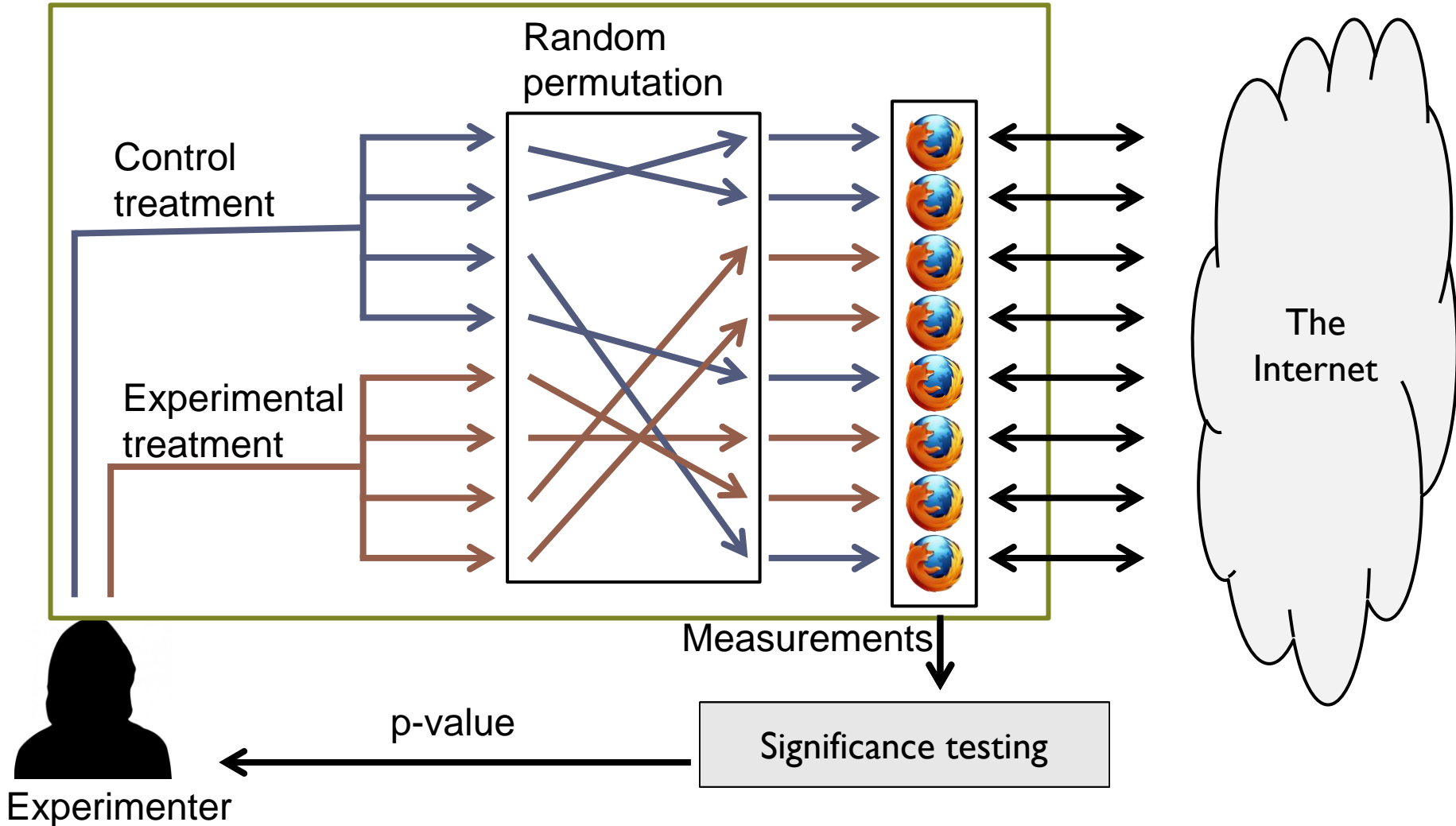
AdFisher Methodology



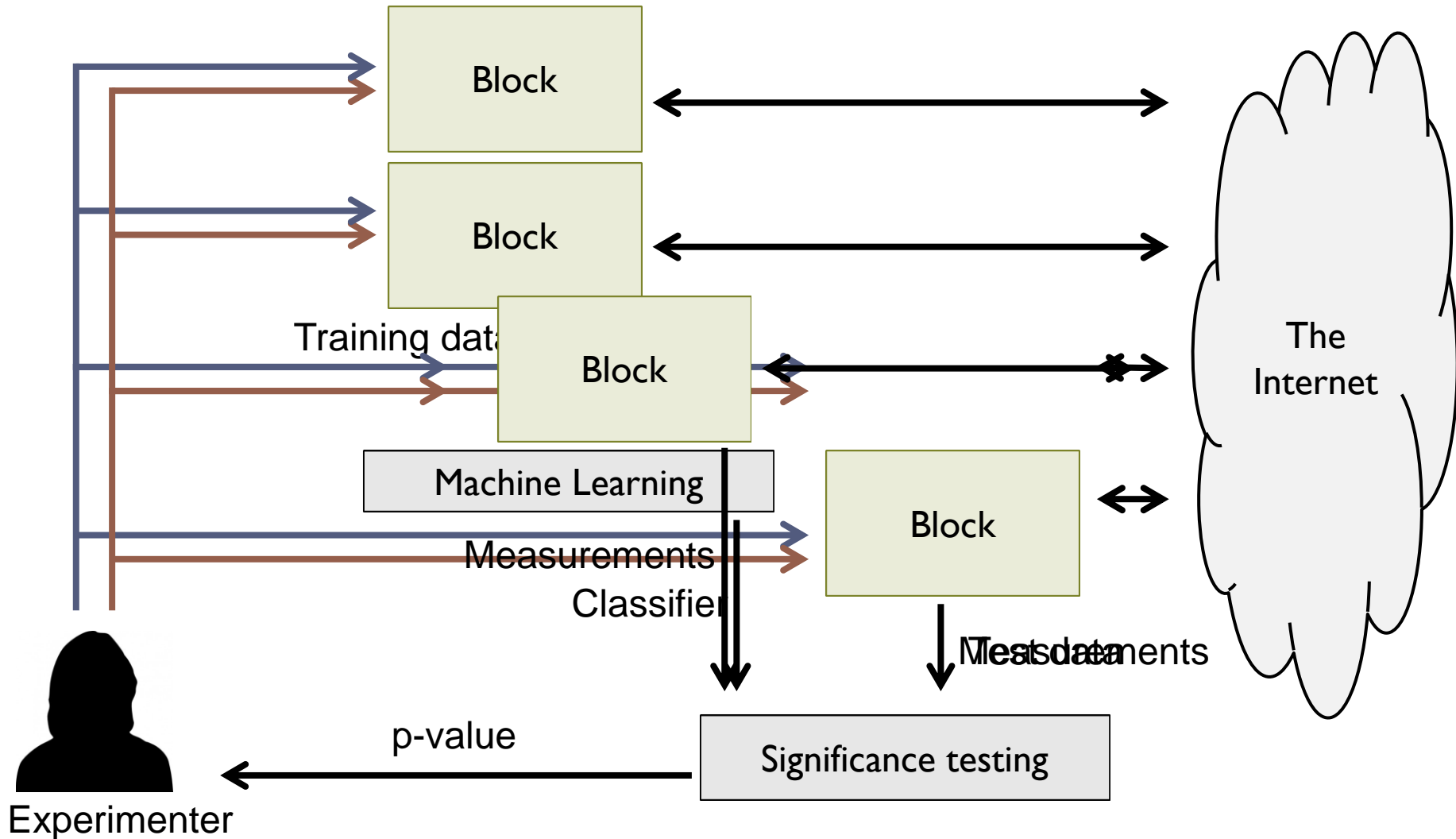
AdFisher Methodology



AdFisher Methodology



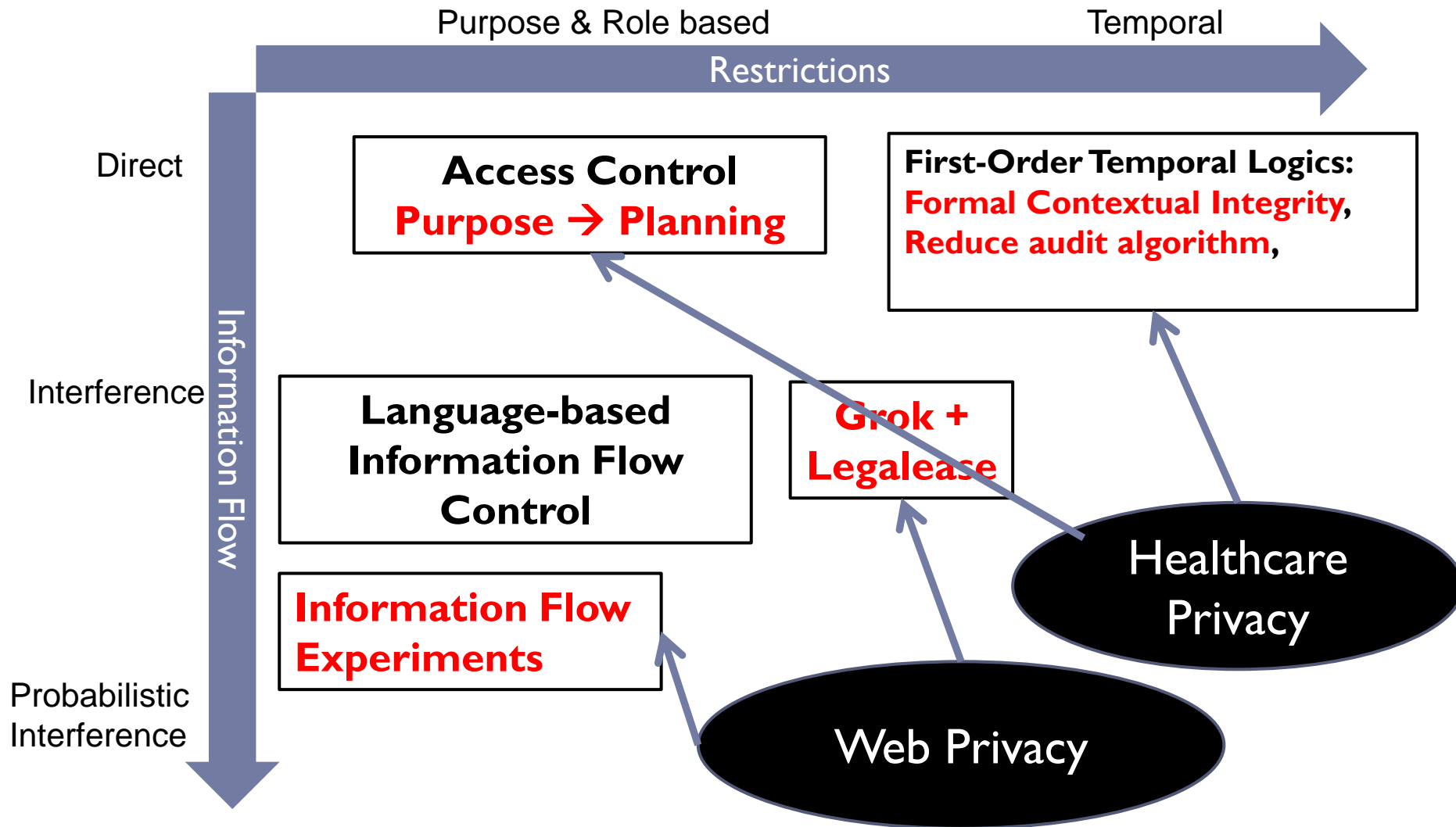
AdFisher Methodology



Prior Work on Behavioral Marketing

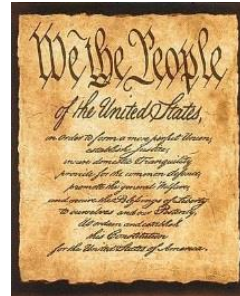
Authors	Test	Limitation
Guha et al.	Cosine similarity	No statistical significance
Balebako et al.	Cosine similarity	No statistical significance
Wills and Tatar	Ad hoc examination	No statistical significance
Liu et al.	Process of elimination	No statistical significance
Barford et al.	χ^2 test	Assumes ads identically distributed
Lécuyer et al.	Parametric Model	Correlation, not causation; assumes ads are independent

Privacy as Restrictions on Personal Information Flow



Privacy through Accountability: An Emerging Research Area

- ▶ Privacy as a right to restrictions on personal information flow
- ▶ Computational accountability mechanisms for enforcement



<http://www.andrew.cmu.edu/user/danupam/privacy.html>



Interference and Causation

Defined in terms of an automation

- ▶ Theorem. A system has probabilistic **interference** iff there exists low inputs ℓ of length t such that the high-level inputs up to t has an **effect** on the low-level outputs up to t given that the low-level inputs were ℓ .

Defined in terms of a structural equation model

Experiment 1: Significant Opacity

Statistical
significance

Experiments	Blocks	# ads (# unique ads)			accuracy	p-value	computation times	
		experimental	control	total			training	testing
Substance abuse	100	20,420 (427)	22,204 (530)	42,624 (673)	81%	0.000005298	18s	3m19s
Disability	100	19,787 (546)	23,349 (684)	43,136 (954)	75%	0.000005298	21s	3m18s
Mental disorder	100	22,303 (407)	22,257 (465)	44,560 (600)	59%	0.0529655	31s	3m19s
Infertility	100	22,438 (605)	22,544 (625)	44,982 (856)	57%	0.113977	39s	3m23s
Adult websites	100	17,670 (602)	17,760 (580)	35,430 (850)	52%	0.416935	33s	3m28s

Table 1: Results from opacity experiments

- ▶ Substance abuse: significant effect on ads, **no effect** on ad settings
- ▶ Disability: significant effect on ads, **“unrelated” effect** on ad settings

Experiment 1: Opacity Explanation

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

Experiment 2: Choice Buttons have Effect

Statistical significance

Experiment	Blocks	# ads (# unique ads)			accuracy	p-value	computation times	
		removed/opt-out	keep/opt-in	total			training	testing
Opting out	54	9,029 (139)	9056 (293)	18,085 (366)	83.3%	0.000005298	4s	2m10s
Dating	100	17,975 (518)	17,762 (457)	35,737 (669)	74%	0.000005298	13s	3m27s
Weight Loss	83	15,826 (367)	15,449 (427)	31,275 (548)	60%	0.040948	16s	3m04s

Experiment 2: Choice Explanation

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

Experiment 3: Discrimination Explanation

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	0.340	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	0.220	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