



CS498—  
Computational  
Advertising

Hari Sundaram

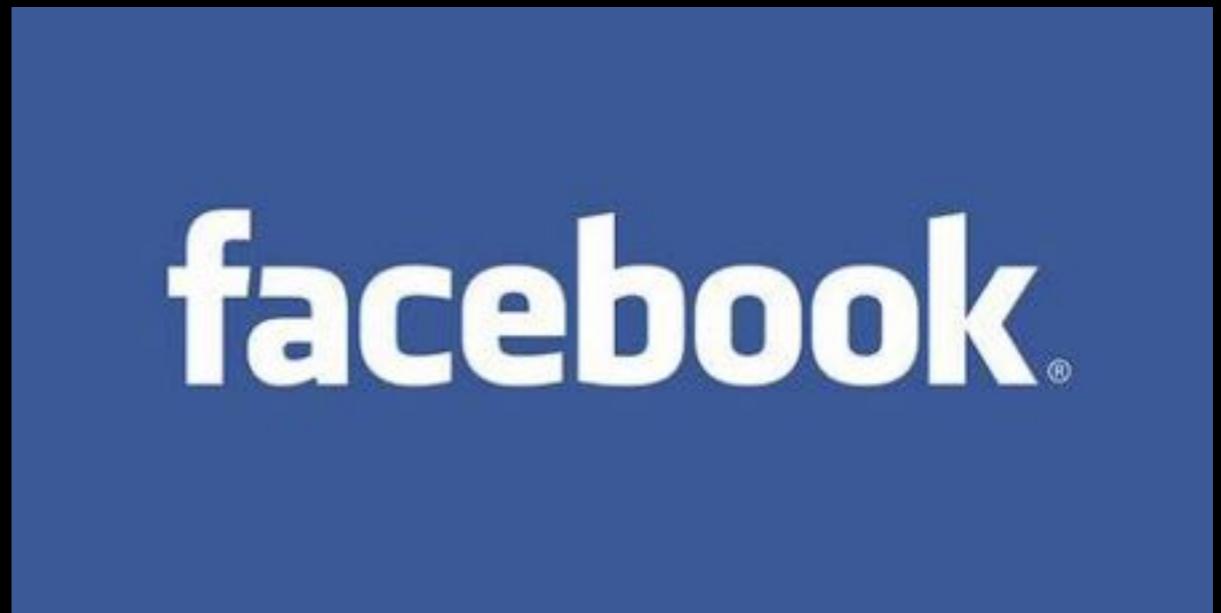
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The landscape of advertising has changed dramatically



leading to large scale consolidation and restructuring within the industry



**Google and Facebook are dominant players  
critical decisions are made by algorithms**

This is an exciting time  
to be in computational  
advertising, as there is  
plenty of uncharted  
territory; the area is ripe  
to support new  
entrepreneurial ideas

# New CS+ADV major

get in touch with your  
academic advisor about  
transfers.

“The best minds of my generation are thinking about how to make people click ads.”

Jeff Hammerbacher

# CS498 Objective:

“The best minds of my generation are thinking <sup>critically</sup> about how to make people ~~click~~ ads.”

# a brief introduction to my research

# Shaping Crowd behavior



# Transportation



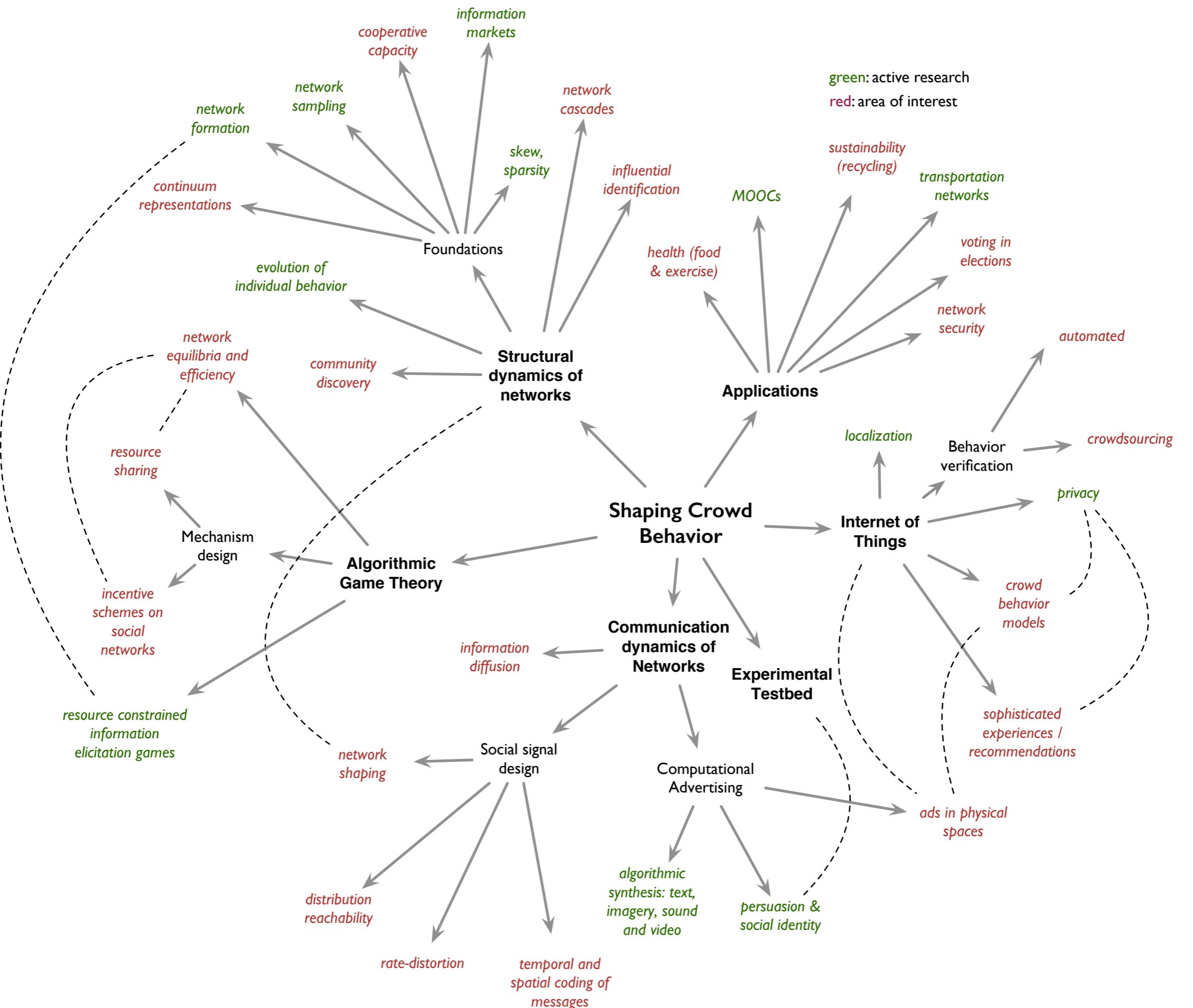


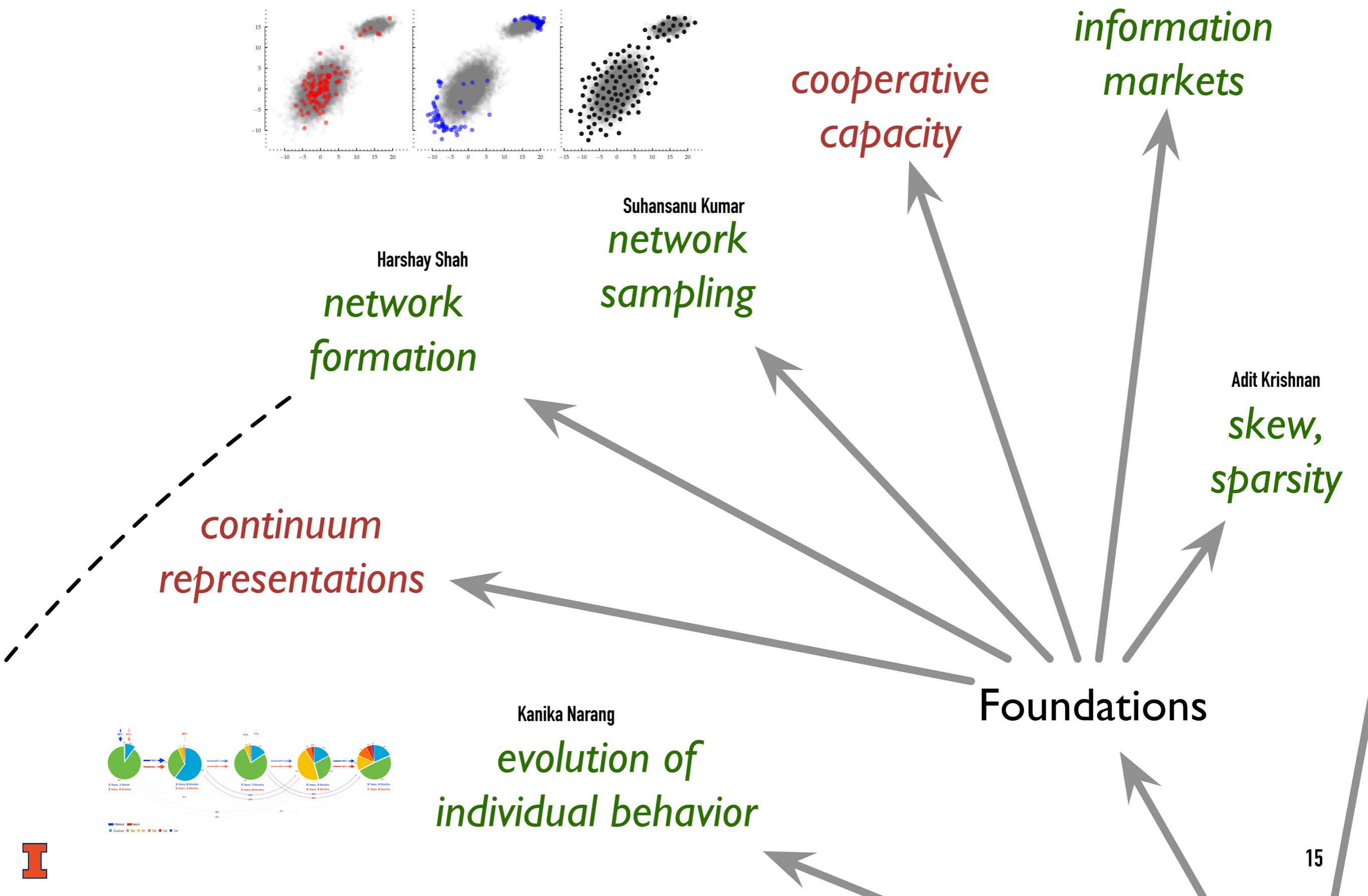
Public Health

How do we persuade millions  
to adopt behaviors beneficial to  
them, and to society at large?

My research lies at the  
intersection of networks and  
computational advertising.

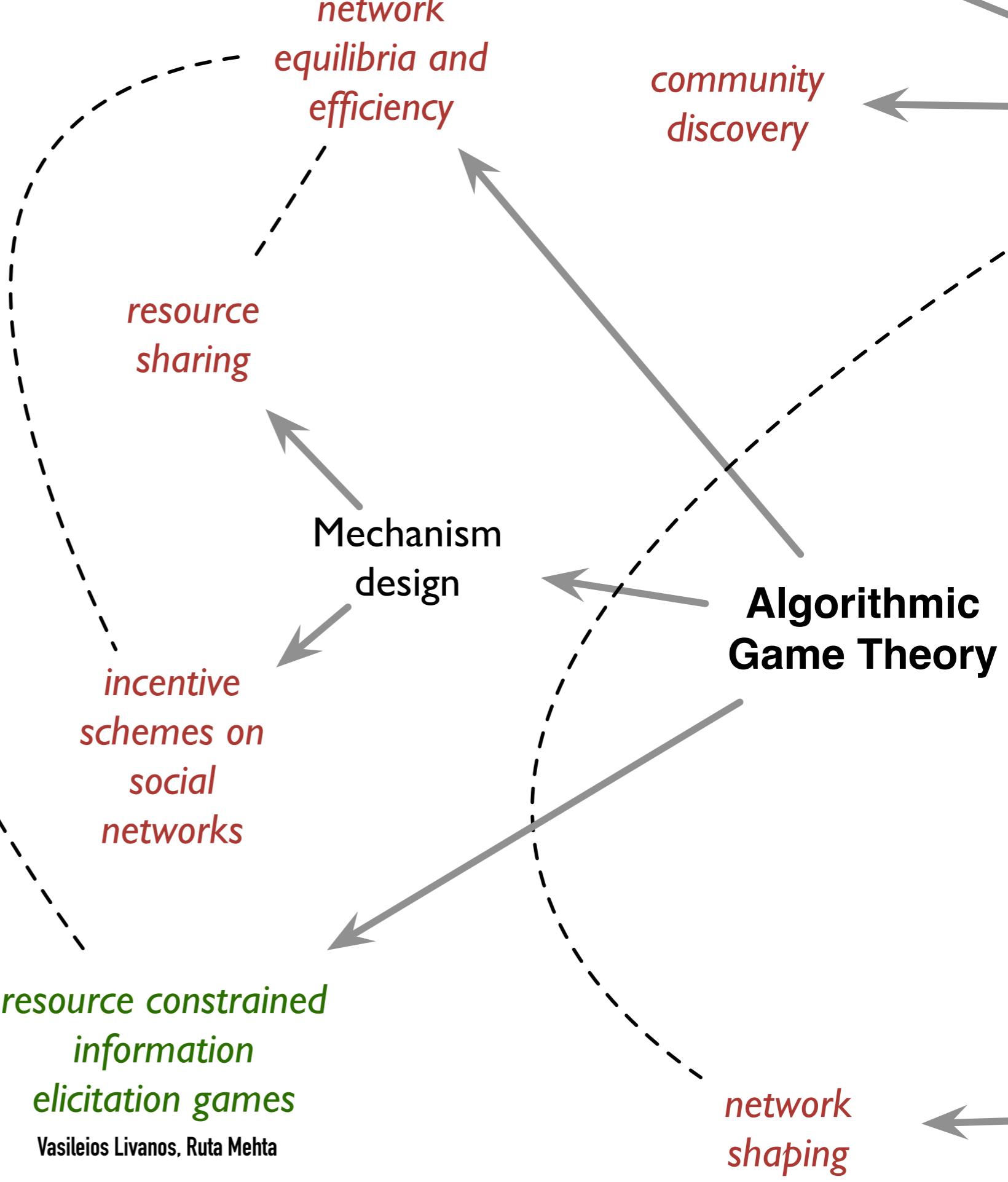
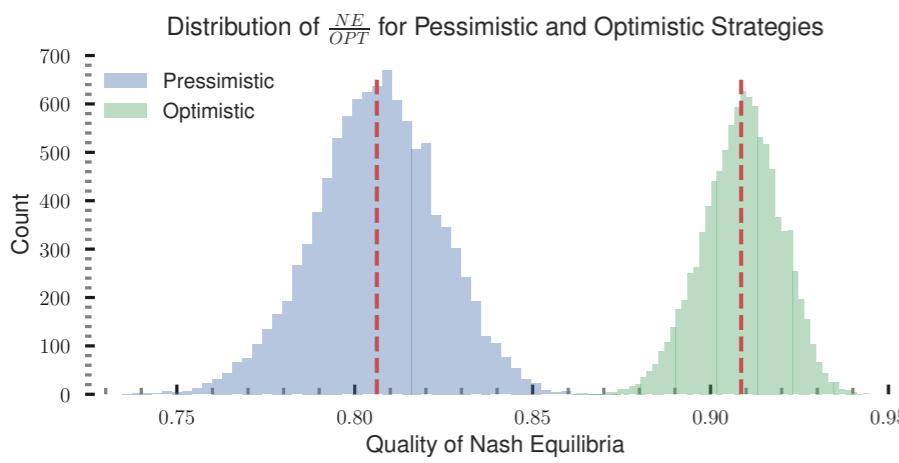
The goal: to shape human  
behavior at scale.

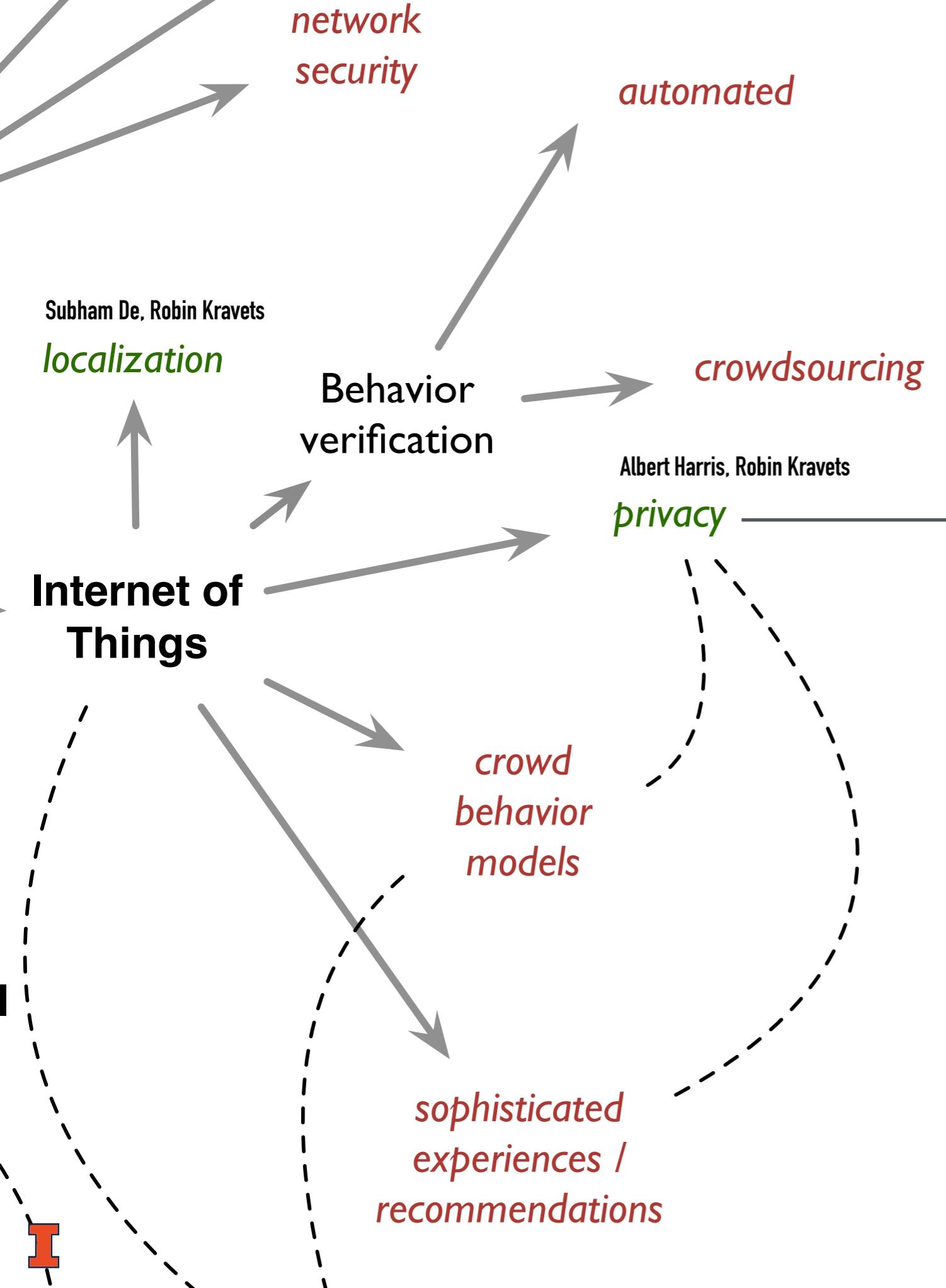




how to sample large attributed graphs?

“...the fundamental scarce resource in the economy is the availability of human time...” Juster & Stafford 1991





What if individuals willingly revealed private information in exchange for services, **but didn't trust** the corporation that we revealed it to?  
**Incognito**

Data Mining and IoT  
Systems co-design

# Experimental Testbed



How to conduct “in the wild” experiments?

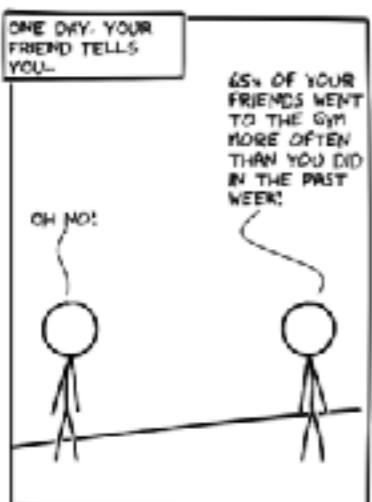
Ziang Xiao

*sophisticated experiences / recommendations*

## Computational Advertising

Ziang Xiao

*algorithmic synthesis: text, imagery, sound and video*



*persuasion & social identity*

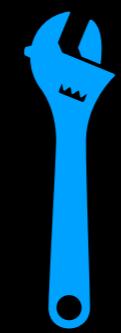
Ziang Xiao

*ads in physical spaces*

Social identities are fluid and change over the course of the day:  
How does social identity affect persuasion?

Can we **synthesize** personalized, persuasive messages algorithmically?

If you are interested in  
my research, drop me  
an email! I'll be happy to  
meet



# Logistics

# Course information:

Website: <https://wiki.illinois.edu/wiki/display/CS498FA18>

Piazza signup: [piazza.com/illinois/fall2018/cs498](https://piazza.com/illinois/fall2018/cs498)



TA's: Subham De (de5), Adit Krishnan (aditk2)

office hours: Fridays 3–4pm 2113 Siebel Center

Prof. Sundaram's office hours: 4–5pm, Wednesdays, 2126 Siebel Center

3 credit {

- MP's = 60% (4 assignments)
- In class presentation: 10%
- Final Project = 30%

# Class components

4 credit {

- MP's + in-class presentation scores scaled to weigh 60%
- Final Project = 40%

# MP's

**Each MP is related to the  
topic taught in the  
previous two weeks**

**Goal: understand a key algorithm  
work with large scale datasets**

**10 min + 5 min Q&A**  
**typically on Fridays**

# In-class presentations

**group work**  
**pick a company in the comp-ad space; describe business model; what is the product, what is the value proposition? who are the customers? who are the competitors? what are the weaknesses?**  
**we will provide example presentations**

# Final project

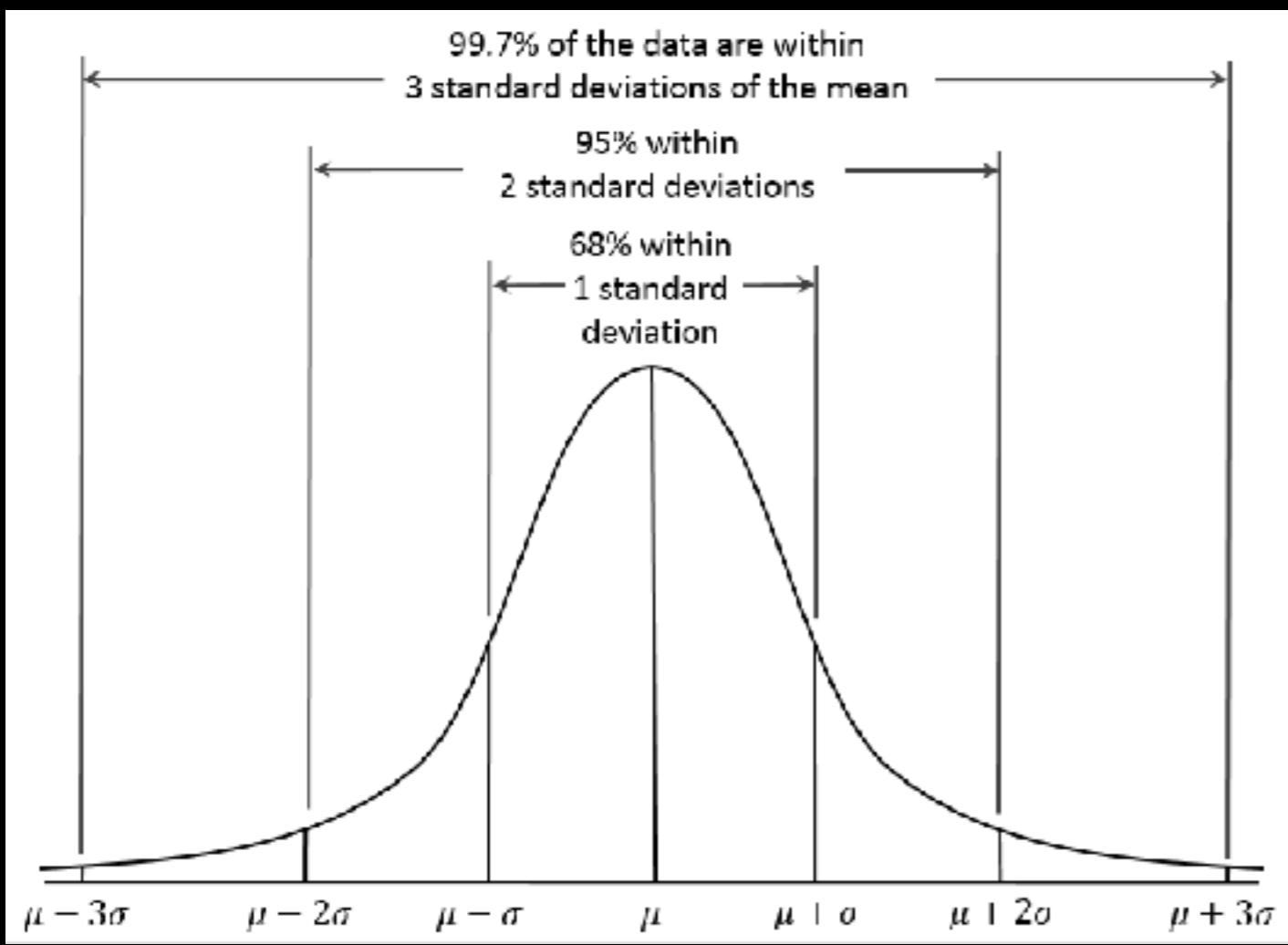
**Goal: exposure to non-trivial aspects of comp-adv  
you can pick any topic of interest to this class  
we will also suggest two different project ideas**

**mid-term checkpoint**

**final presentation**

**final report**

**expect that best projects be submitted to conferences**



Will grade on a curve  
Will grade undergrads and  
grads on the **same** curve—  
there is no difference in  
performance.

Note: In Spring 2018, the  
median grade for CS 412  
was '**A-**'

# We will use CATME to form groups

groups of at most 3 people

same group throughout the semester

look out for an email!

The group gets a  
common grade for the  
work

**MP's are individual assignments  
groups are for  
presentations and  
final project**

What if you find that  
your partners are free-  
riding? or if you have a  
free-rider?

Give two weeks notice,  
before the assignment is  
due, to your partners,  
that you are leaving.

Inform the TA's that you are leaving this group

Then, you will work by yourself,  
and the remainder of your group  
will submit separately

You cannot form a new group, or join another

# academic integrity

**zero tolerance** policy!

since the grades are  
determined on a curve,  
academic dishonesty  
affects other students'  
grades

You are encouraged to form a study group to discuss the homework and the programming assignments but are expected to compete the homework and programming assignments **completely on your own, without recourse to notes from the group discussions.**

**Plagiarism:** It is an academic violation to copy, to include text from other sources, including online sources, without proper citation.

Any student found to be  
violating this code will  
be subject to  
**disciplinary** action.

# Computational advertising: a brief tour



Introduction



Web search



Game Theory



Auctions



Text Ads



Display Ads



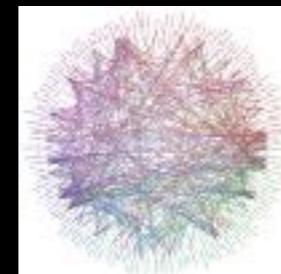
Behavioral targeting



Recommender systems



Privacy



Networks



Emerging areas



Final Presentations

# Computational advertising: a new discipline

A new scientific sub-discipline, bringing together

- Information retrieval
- Large scale search and text analysis
- Statistical modeling
- Machine learning
- Microeconomics
- Algorithmic Game Theory, auction theory, mechanism design
- Classification
- Optimization
- Recommender systems, ...

Advertising is a market  
where each side cares  
                          
about the type of the  
other side



Advertisers want the attention  
of certain people

People are only open to certain ads  
(whether or not in the market for the  
advertised good)

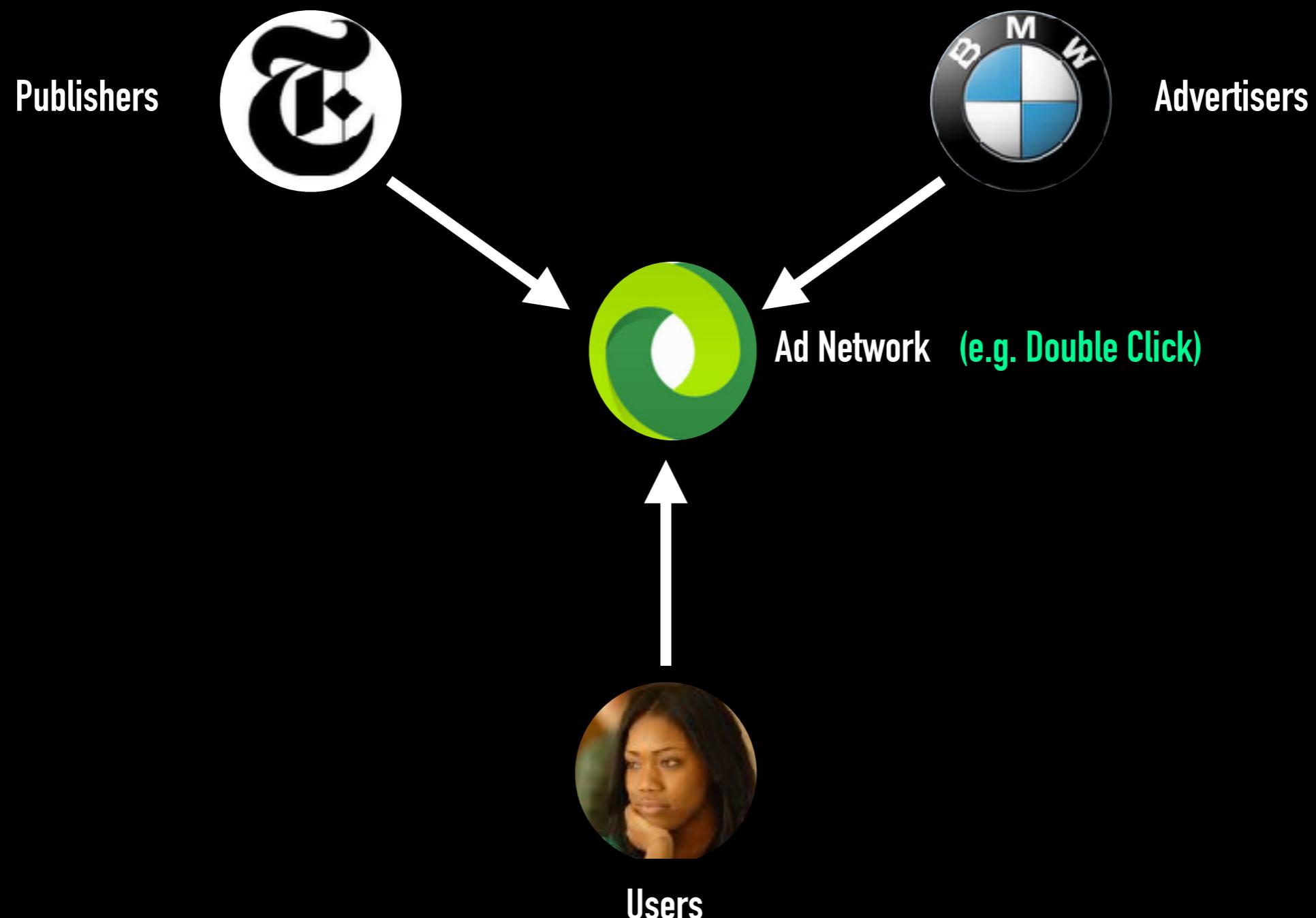


# A key challenge:

**Find the "best match" between a given user in a  
given context and a suitable advertisement.**

contexts: web search; publisher page (e.g. NY Times); mobile; billboard etc.

# key actors



Huge financial  
implications

## Revenues

The following table presents our revenues, by segment and revenue source (in millions, unaudited):

	Three Months Ended		Six Months Ended	
	June 30,		June 30,	
	2017	2018	2017	2018
<b>Google segment</b>				
Google properties revenues	\$ 18,425	\$ 23,262	\$ 35,828	\$ 45,260
Google Network Members' properties revenues	4,247	4,825	8,255	9,469
Google advertising revenues	22,672	28,087	44,083	54,729
Google other revenues	3,241	4,425	6,448	8,779
Google segment revenues	25,913	32,512	50,531	63,508
<b>Other Bets</b>				
Other Bets revenues	97	145	229	295
<b>Revenues</b>	<b>\$ 26,010</b>	<b>\$ 32,657</b>	<b>\$ 50,760</b>	<b>\$ 63,803</b>

Google's ad revenue is 86% of total  
For Facebook, this is 97%

Advertising is the  
primary mechanism that  
sustains “free” online  
services and content

should content be free?

There are huge privacy  
implications too

June 1994: Netscape makes a cookie

at each website,  
we leave a digital  
**trail** of our  
activities





Our histories are **bought** and **sold** in real time

A close-up photograph of two hands, one light-skinned and one dark-skinned, holding a red octagonal stop sign. The sign features the words "STOP" on top and "AIDS" below it, both in white, bold, sans-serif capital letters. The background is plain white.

people worry about a dystopian future

STOP  
AIDS

Is all or nothing the only  
option?

we don't have fine grained control

despite the cookie being  
created nearly 25 years  
ago, we've only started

Over the past 10 years,  
traditional advertising agencies  
are consolidating, and are  
transforming themselves

# how do we get here?



should we?

Ads on the web are not  
as compelling as the  
ones in glossy magazines

we don't yet understand  
how to synthesize,  
personalized, compelling  
ads on the fly

today, we are  
**exchanging** our privacy  
for free services

does it have to be that way?



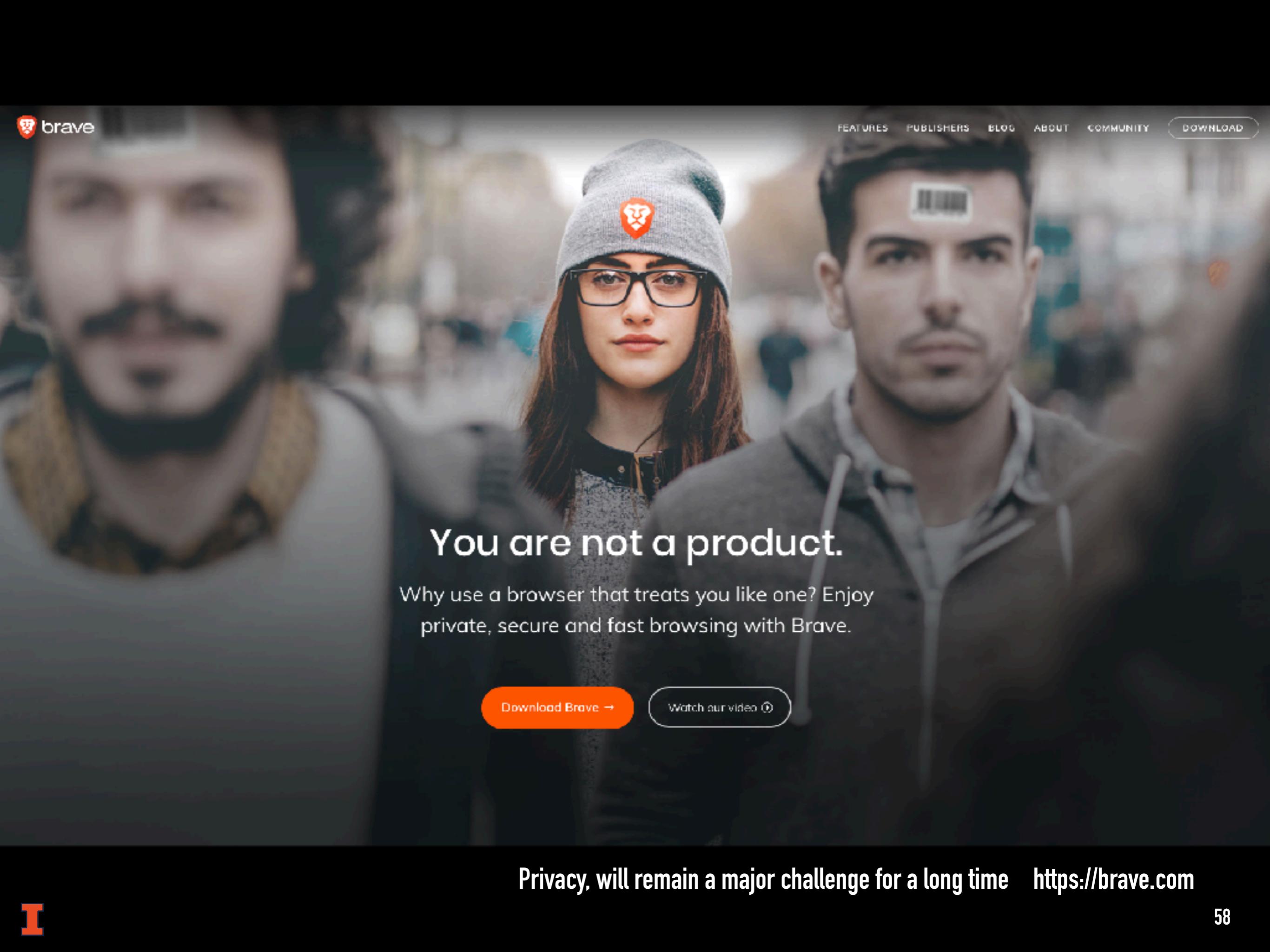
# A simple idea

what if individuals **willingly** revealed  
their preferences in return for services?

but didn't trust the  
corporation that we  
revealed it to?

incognito  
hari sundaram & robin kravets

is it possible to hide?



## You are not a product.

Why use a browser that treats you like one? Enjoy private, secure and fast browsing with Brave.

[Download Brave →](#)[Watch our video](#) 

Privacy, will remain a major challenge for a long time <https://brave.com>

# Why computational advertising?

# Classic advertising has a rich history



# branding

create a distinct favorable image



You never actually own  
a Patek Philippe.

You merely look after it for  
the next generation.

175  
PATEK PHILIPPE



Annual Calendar Ref. 5205G  
[patek.com](http://patek.com)

# to drive sales



Wearnes Autohaus

BMW

Sheer  
Driving Pleasure

[www.wearneautohaus.com.my](http://www.wearneautohaus.com.my)

THE SIGNIFICANT  
ANNUAL SPECIAL.

### **Classical:**

**Relatively few venues – magazines, billboards, newspapers, handbills, TV, etc**

**High cost per venue (\$3Mil for a Super Bowl TV ad)**

**Limited personalization possible**

**Targeting by the wisdom of ad-people**

**Hard to measure ROI**

“Half the money I spend on advertising is wasted; the trouble is, I don't know which half.”

John Wanamaker (1838-1922)

# why go computational?

**Computational – almost the exact opposite:**  
**Billions of opportunities**  
**Billions of creatives**  
**Totally personalized**  
**Tiny cost per opportunity**  
**Much more quantifiable**

# Decomposing the challenge:

**Find the "best match" between a given user in a given context and a suitable advertisement.**

**contexts: web search; publisher page (e.g. NY Times); mobile; billboard etc.**

# related challenges

**Design markets and exchanges**  
that help in this task, and  
maximize value for users,  
advertisers, and publishers

Build the  
**infrastructure** to  
support this process

# Decomposing the challenge:

**Find the "best match" between a given user in a given context and a suitable advertisement.**

contexts: web search; publisher page (e.g. NY Times); mobile; billboard etc.

**Represent** the user, the context, and the ads in an effective & efficient way

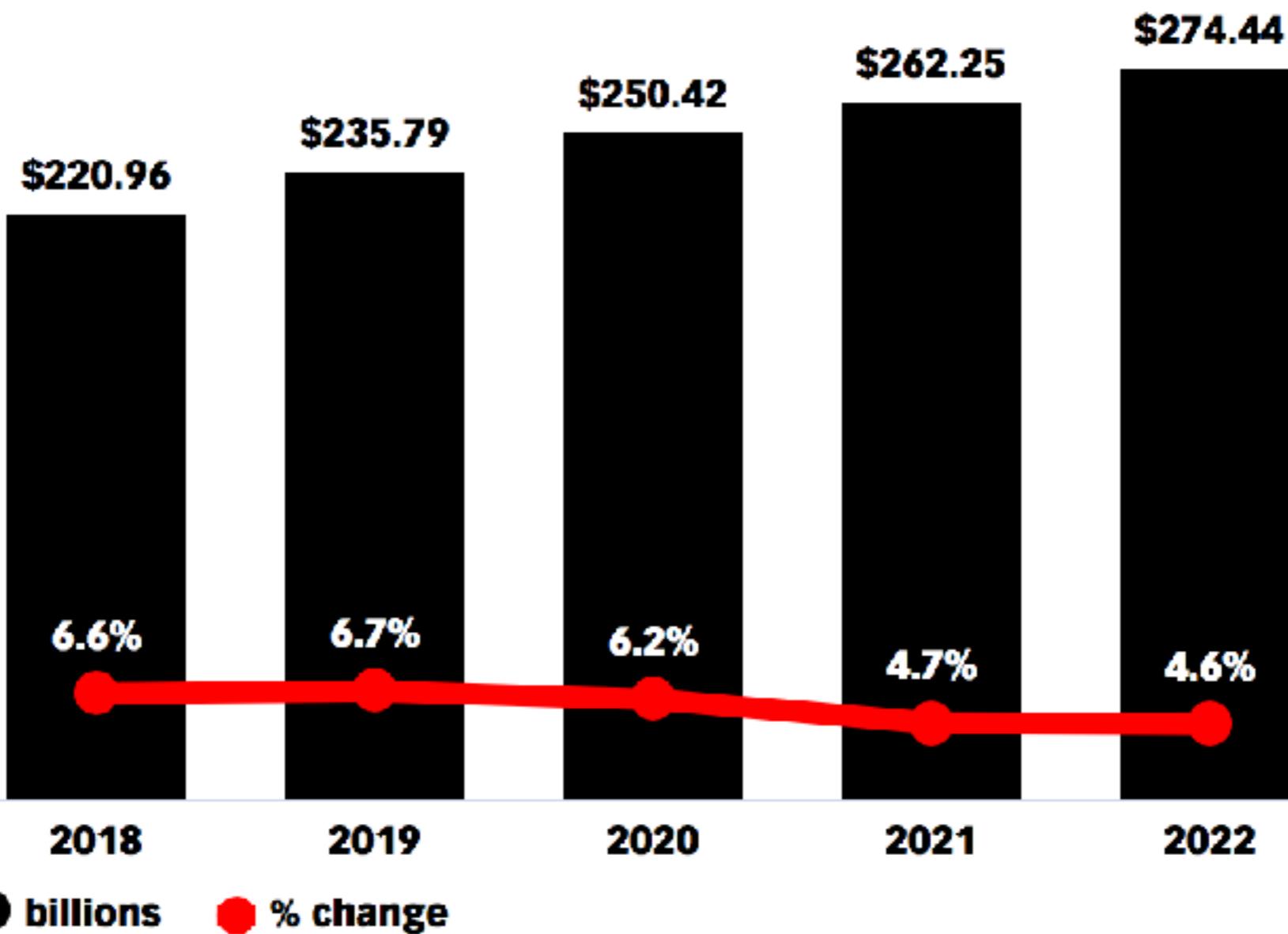
**Define** the mathematical optimization problem to capture the actual marketplace constraints and goals

**Solve** the optimization problem in an effective & efficient way

# The landscape

## Total Media Ad Spending

US, 2018-2022



Source: eMarketer, March 2018

[www.emarketer.com](http://www.emarketer.com)

## Average Daily Time Spent with Media Among US Consumers, 2014-2020

minutes

	2014	2015	2016	2017	2018	2019	2020
<b>TV</b>	<b>297.8</b>	<b>289.0</b>	<b>287.4</b>	<b>282.1</b>	<b>276.8</b>	<b>271.5</b>	<b>266.2</b>
<b>Internet</b>	<b>154.9</b>	<b>180.0</b>	<b>189.0</b>	<b>217.0</b>	<b>239.9</b>	<b>265.2</b>	<b>274.0</b>
—Mobile*	88.1	124.0	136.0	164.0	187.9	214.2	223.0
—Desktop	66.9	56.0	53.0	53.0	52.0	51.0	51.0
<b>Radio</b>	<b>111.0</b>	<b>109.0</b>	<b>104.5</b>	<b>102.0</b>	<b>100.0</b>	<b>99.0</b>	<b>97.3</b>
<b>Magazines</b>	<b>19.6</b>	<b>18.6</b>	<b>17.6</b>	<b>16.5</b>	<b>15.2</b>	<b>14.0</b>	<b>12.7</b>
<b>Newspapers</b>	<b>19.6</b>	<b>17.0</b>	<b>15.0</b>	<b>14.0</b>	<b>12.4</b>	<b>11.0</b>	<b>9.5</b>

Note: \*includes browsers and apps

Source: comScore Inc., Media Dynamics Inc., Nielsen, Nielsen Audio and Zenith forecasts as cited in Zenith, "Media Consumption Forecasts 2018," May 29, 2018

## Total Media Ad Spending, by Media

US, 2018, billions

### Digital



### Mobile



### TV



### Print



### Radio



### Out-of-home



### Directories



Source: eMarketer, July 2018

[www.emarketer.com](http://www.emarketer.com)

Net US Digital Ad Revenues, by Company, 2016-2020					
	billions, % change and % of total				
	2016	2017	2018	2019	2020
<b>Google</b>	<b>\$29.43</b>	<b>\$34.87</b>	<b>\$39.92</b>	<b>\$45.51</b>	<b>\$51.66</b>
—% change	19.3%	16.5%	14.5%	14.0%	13.5%
—% of total	10.8%	38.6%	37.2%	36.2%	36.3%
<b>Facebook</b>	<b>\$12.37</b>	<b>\$17.97</b>	<b>\$21.00</b>	<b>\$24.20</b>	<b>\$27.43</b>
—% change	52.8%	45.3%	16.9%	15.2%	13.4%
—% of total	17.1%	19.9%	19.6%	19.2%	19.3%
<b>Microsoft (Microsoft and LinkedIn)</b>	<b>\$3.34</b>	<b>\$3.74</b>	<b>\$4.16</b>	<b>\$4.46</b>	<b>\$4.74</b>
—% change	38.4%	12.0%	11.0%	7.3%	6.2%
—% of total	4.6%	4.1%	3.9%	3.5%	3.3%
<b>Oath</b>	<b>\$1.27</b>	<b>\$3.60</b>	<b>\$3.69</b>	<b>\$3.77</b>	<b>\$3.84</b>
—% change	4.7%	184.7%	2.3%	2.2%	2.0%
—% of total	1.8%	6.0%	3.6%	3.0%	2.7%
<b>Amazon</b>	<b>\$1.12</b>	<b>\$1.77</b>	<b>\$2.89</b>	<b>\$4.37</b>	<b>\$6.37</b>
—% change	58.0%	56.5%	63.5%	51.0%	46.0%
—% of total	1.5%	2.0%	2.7%	3.5%	4.5%
<b>Twitter</b>	<b>\$1.36</b>	<b>\$1.17</b>	<b>\$1.12</b>	<b>\$1.18</b>	<b>\$1.22</b>
—% change	6.4%	-13.6%	-4.9%	5.5%	3.8%
—% of total	1.9%	1.3%	1.0%	0.9%	0.9%
<b>Yelp</b>	<b>\$0.62</b>	<b>\$0.71</b>	<b>\$0.83</b>	<b>\$0.97</b>	<b>\$1.10</b>
—% change	31.5%	15.6%	17.0%	16.0%	14.0%
—% of total	0.9%	0.8%	0.8%	0.8%	0.8%
<b>Snapchat</b>	<b>\$0.30</b>	<b>\$0.57</b>	<b>\$1.03</b>	<b>\$1.81</b>	<b>\$3.08</b>
—% change	446.1%	88.4%	81.7%	75.7%	70.0%
—% of total	0.4%	0.6%	1.0%	1.4%	2.2%
<b>IAC</b>	<b>\$0.50</b>	<b>\$0.47</b>	<b>\$0.45</b>	<b>\$0.45</b>	<b>\$0.45</b>
—% change	-29.3%	-5.9%	-2.9%	-1.6%	-0.2%
—% of total	0.7%	0.5%	0.4%	0.4%	0.3%
<b>Hulu</b>	<b>\$0.31</b>	<b>\$0.35</b>	<b>\$0.39</b>	<b>\$0.44</b>	<b>\$0.49</b>
—% change	15.9%	13.0%	13.2%	13.0%	11.4%
—% of total	0.4%	0.4%	0.4%	0.4%	0.3%
<b>Roku</b>	<b>\$0.06</b>	<b>\$0.15</b>	<b>\$0.29</b>	<b>\$0.48</b>	<b>\$0.70</b>
—% change	-	165.0%	93.0%	62.4%	47.3%
—% of total	0.1%	0.2%	0.3%	0.4%	0.5%
<b>Yahoo</b>	<b>\$2.25</b>	-	-	-	-
—% change	-10.6%	-	-	-	-
—% of total	3.1%	-	-	-	-
<b>Total digital ad spending</b>	<b>\$72.20</b>	<b>\$90.39</b>	<b>\$107.30</b>	<b>\$125.75</b>	<b>\$142.23</b>

Note: includes advertising that appears on desktop and laptop computers as well as mobile phones, tablets and other Internet-connected devices, and includes all the various formats of advertising on those platforms; net ad revenues after companies pay traffic acquisition costs (TAC) to partner sites. Facebook advertising revenues include Instagram advertising revenues.

Source: company reports; eMarketer, March 2018

**CPM** = cost per millie (thousand impressions)

Typically used for graphical/banner ads  
(brand advertising)

Could be paid in advance ("Guaranteed delivery")

**CPC** = cost per click

Typically used for textual ads

# (some) terminology

**CPT/CPA** = cost per transaction/action

a.k.a. referral fees or affiliate fees

Typically used for shopping ("buy from our sponsors"), travel, etc.

But now also used for textual ads (risk mitigation)

we'll introduce additional terminology as needed

**Ads driven by search**

**keywords** = “**sponsored search**” (a.k.a. “**keyword driven ads**”, “**paid search**”, “**adwords**”, etc)

**Advertiser chooses a “bid phrase” = query on which to display**

# textual ads

**Ads driven by the content of a web page** = “**content match**” (a.k.a. “**context driven ads**”, “**contextual ads**”, “**adsense**”, etc)

**Can also subscribe to “advanced match” = display me on related queries**

**Needed to achieve volume  
Huge challenge**

Late 1990s, Alta Vista tried  
the Sponsored Search model

Rejected by the early  
search engine users

Goto.com (acquired later by  
Overture) develops a search  
engine for paid ads

Users with commercial interest  
go to this engine  
At the peak, a billion dollar  
business

Google tries the Sponsored  
Search model again  
This time a success

Advertisers cannot get  
enough volume  
Content match to provide  
more impressions

# text ads: a brief history

## Two types of online graphical advertising

Guaranteed delivery (GD)

Performance graphical advertising (non-guaranteed delivery, NGD)

Guaranteed delivery (GD)

Contract booked based on targeting attributes of an impression: age, income, location, ...

Each contract has a duration and a desired number of impressions

# display ads



## Issues in GD

Contract pricing

Traffic forecasting

Impression allocation

to the active contracts

Graphical ads can also be placed based on performance – CPM/CPC/CPA

Assume that the  
Optimization Problem  
is to maximize CTR

Ads represented by achieved CTR/page + weights

Matching approaches:

**Reactive**: explore the placement of a particular ad on different pages; for each page observe achieved CTR; once the CTRs are learned, given page, pick the ad with highest observed CTR

1

# display ads



**Predictive**: generate features for the ad using related ads (same advertiser), landing page, or advertiser metadata – predict performance based on page and ad features

**Hybrid**: (1) and (2) are complementary and can be combined

2

Ads (pages) represented by features of ads (pages) + weights

# DISPLAY LUMAscape

M  
A  
R  
K  
E  
T  
E  
R

## Agencies

**WPP**

Omnicom Group



**IPG**

**dentsu**

**HAVAS**

**MERKLE**

MDC Partners

**AEGIS**

**AKQA**

**LBI**

**ROSETTA**

**icrossing**

**Innovation INTERACTIVE**

**camelot Mediasmith**

**at&t Interactive**

**IBM**

**essence**

**yodle**

**REACH LOCAL**

**WebVisible**

## Agency Trading Desks

**XAXIS**

**accuen**

**vivaki**

**RUN**

**CADREON**

**amnet accordantmedia**

**AFFI PERF**

**IMPACT**

**VARICKMEDIA MANAGEMENT**

## Creative Optimization

**teracent**

**TUMRI**

**dapper**

**Impossible Software**

**adroit**

**struq**

**MIXPO**

**thunder**

**SPONGECELL**

**engagedclick**

**promote**

**totalAssessing**

**adacado**

**Dynamix**

**snapads**

**AdReady**

**CERTONA**

**richrelevance**

**ADISN**

**Retargeting**

**dotomi**

**criteo**

**MAGNE+IC**

**AdRolls**

**@ Tell Apart**

**crosspixelmedia**

**PERFECT AUDIENCE**

**mediaFORGE**

**MYBUYS**

**FetchBack**

**ReTargeter**

**STEELHOUSE**

**myThing**

**mediaFORGE**

**flashtalking**

**trueeffect**

**adform**

**adgear**

**pictela**

**pointroll**

**ctwonder**

**flashtalking**

**trueeffect**

**adform**

**mediamind!**

**Sizmeki**

**FLITE**

**Mediaplex**

**doubleclick**

**by Google**

**atlas**

**medi**

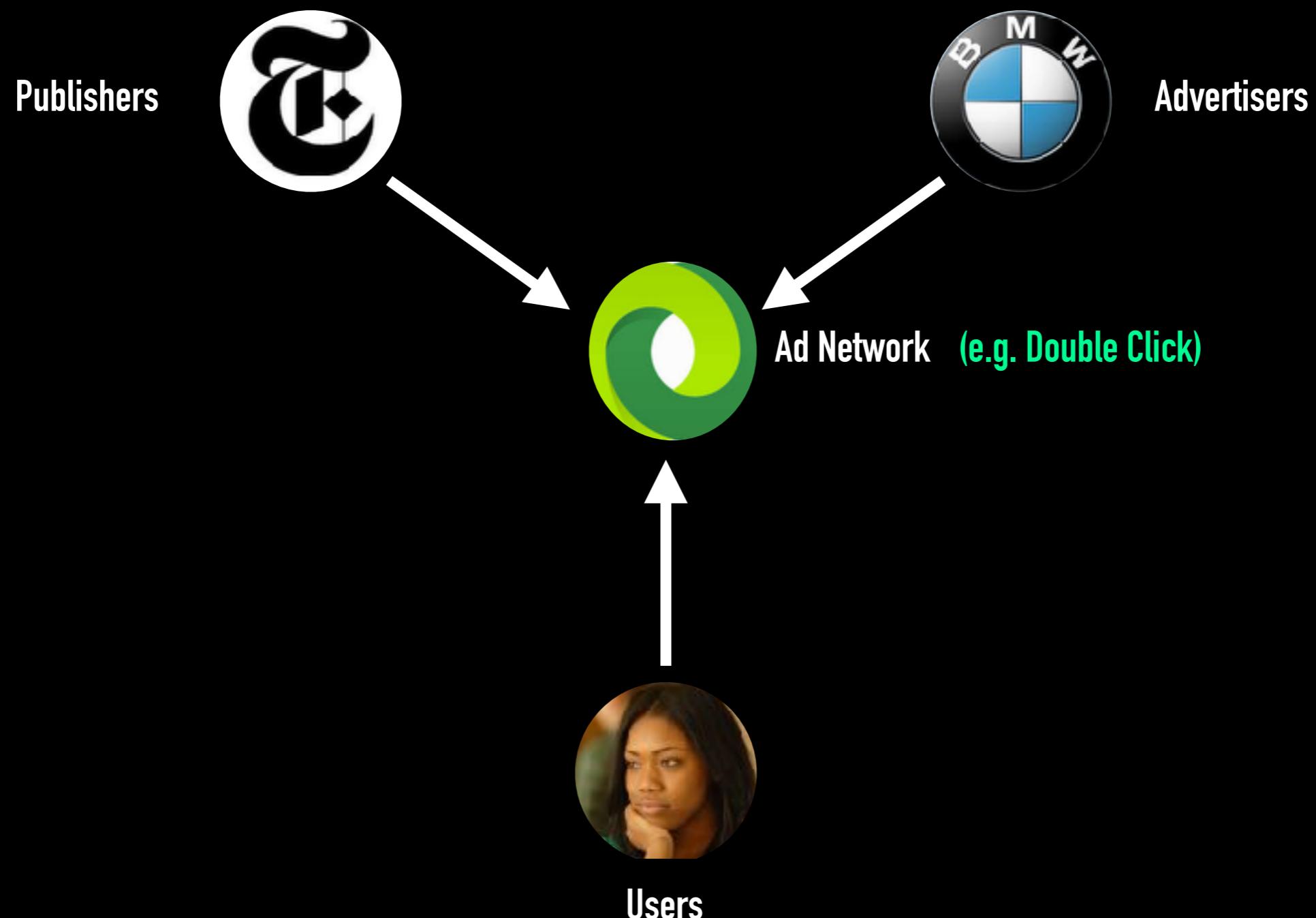
A preview of the next  
few lectures

# A key challenge:

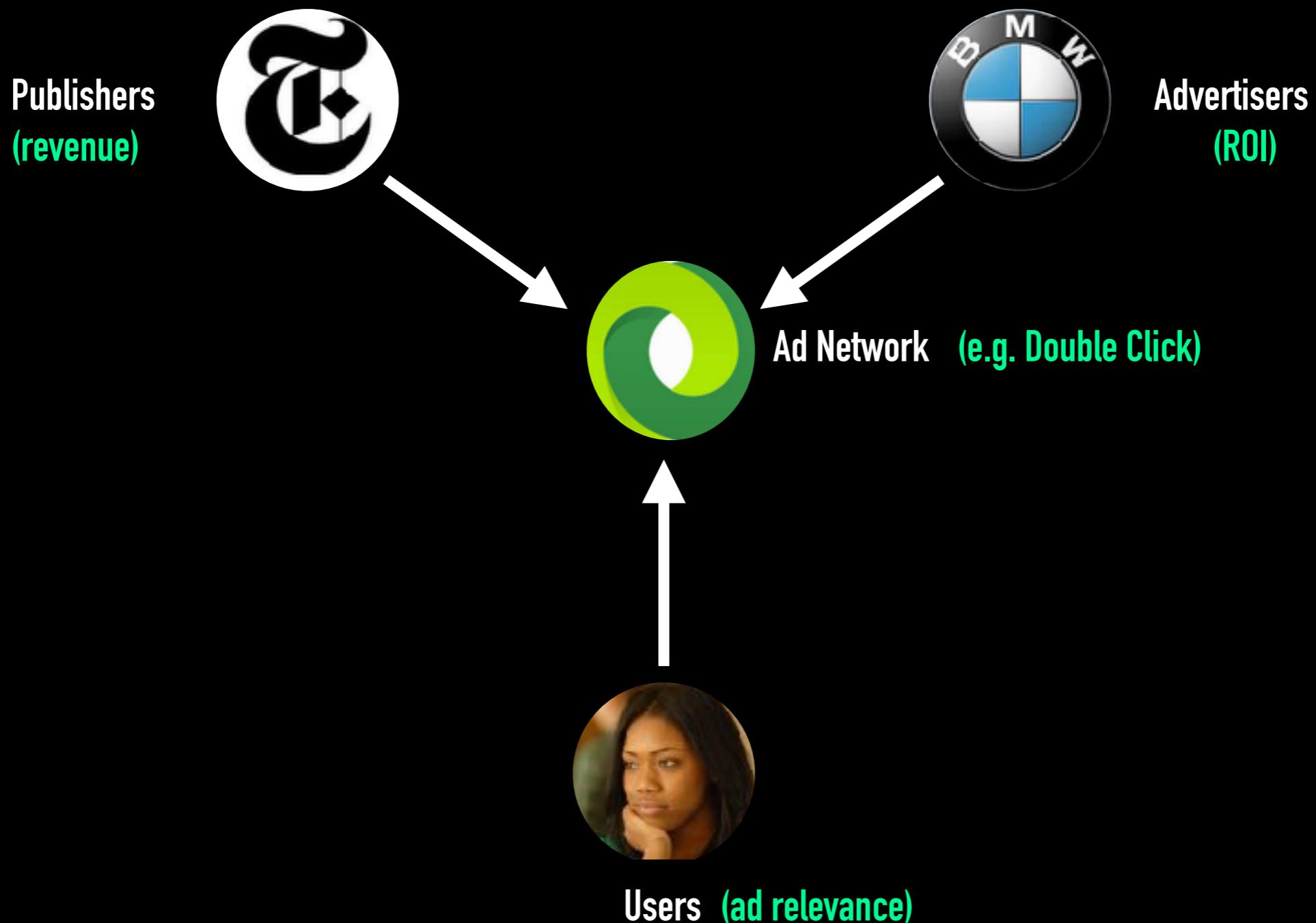
**Find the "best match" between a given user in a  
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contexts: web search; publisher page (e.g. NY Times); mobile; billboard etc.

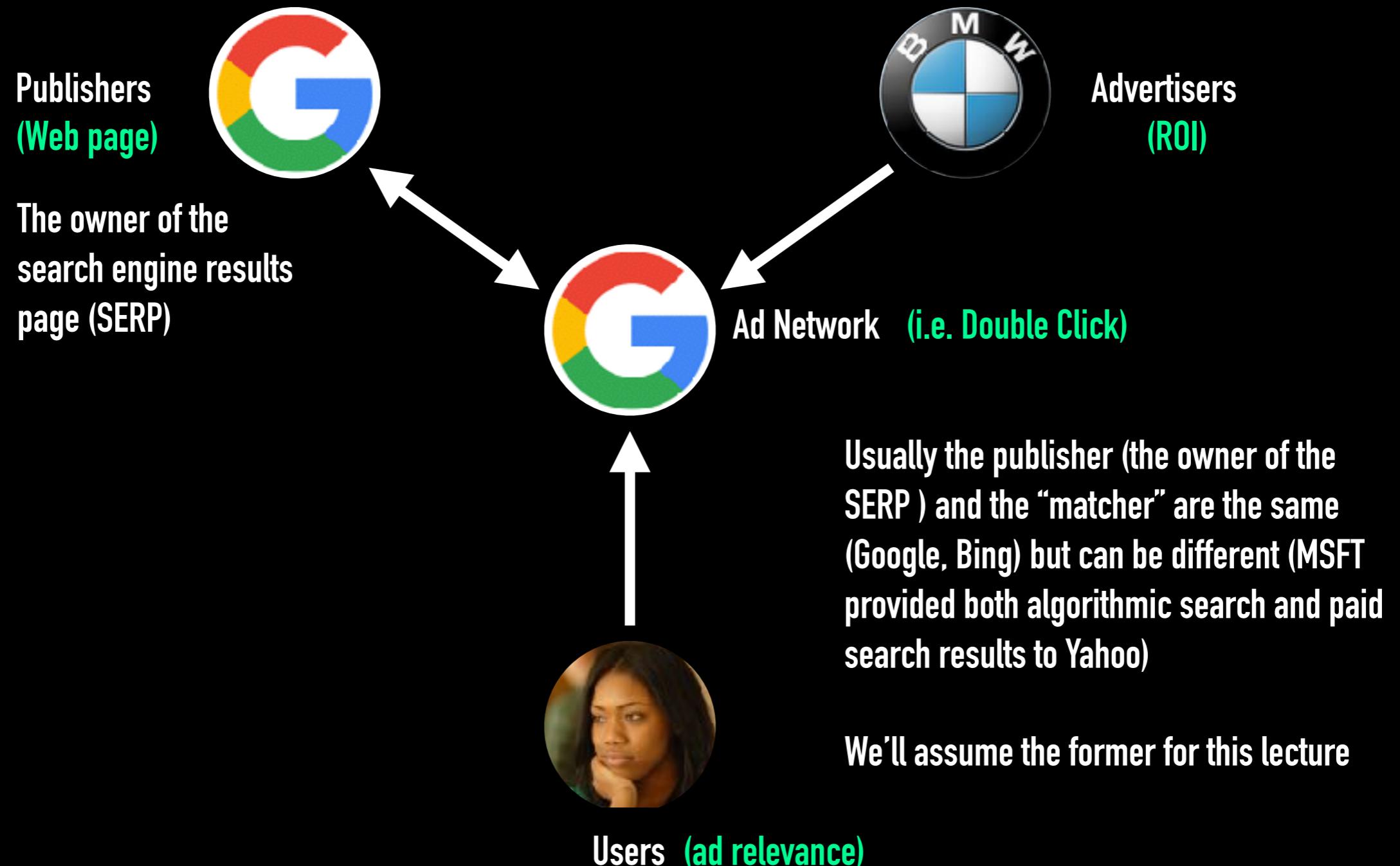
# key actors



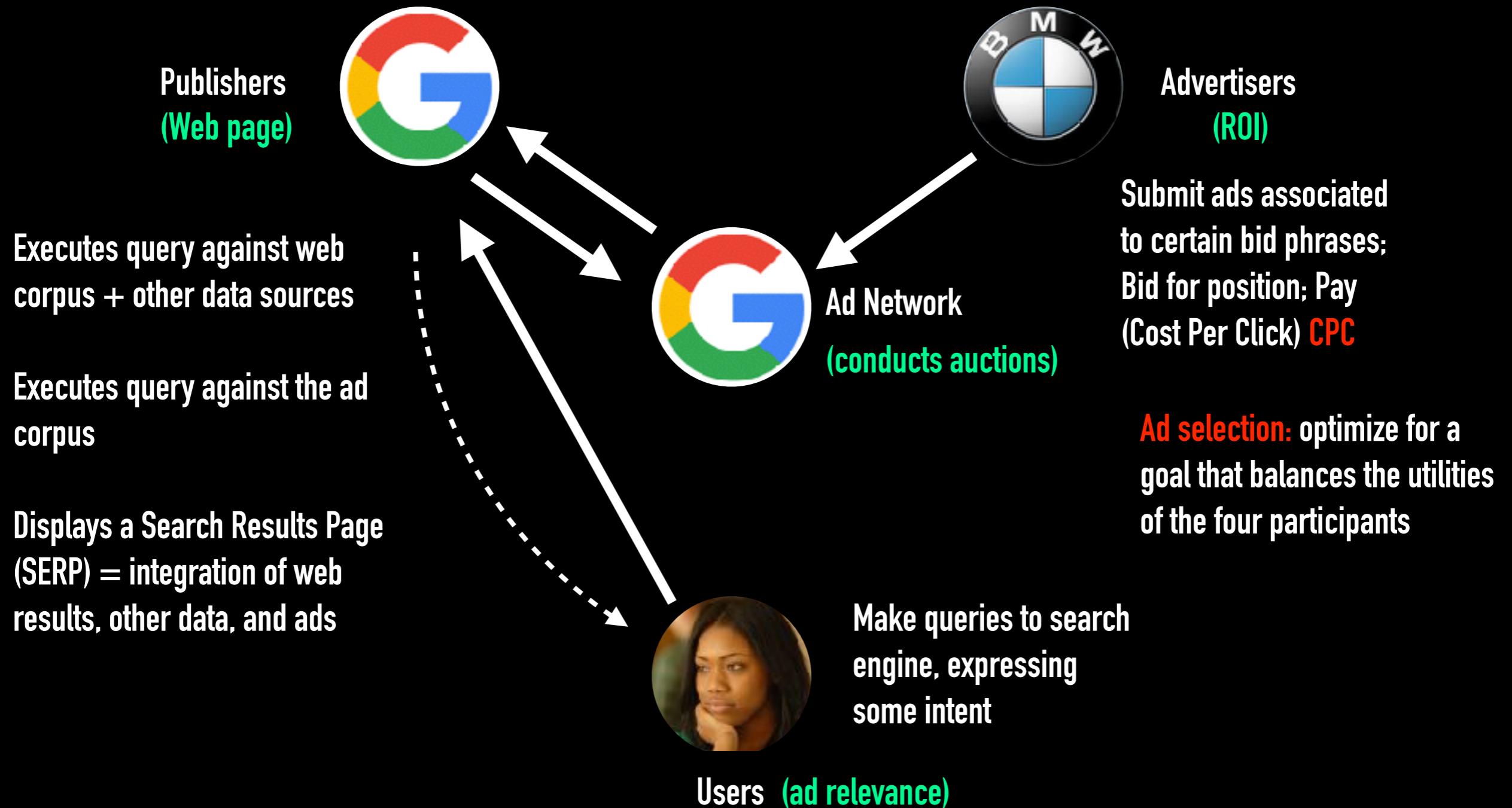
# each actor has a different utility function



# Sponsored Search



# Sponsored Search



Billions of individual ads in sponsored search and content match

Billions of unique queries/millions of searches per hour

Trillions of page impressions (content match and graphical advertising)

Billions of users

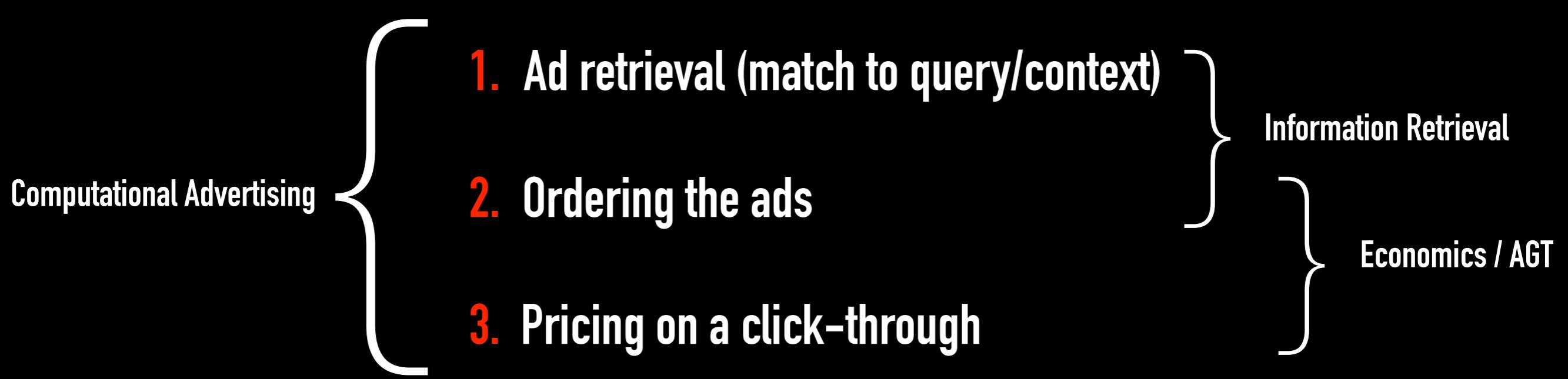
# scale and costs

Requests served while the user 'waits': no more than 100ms response time

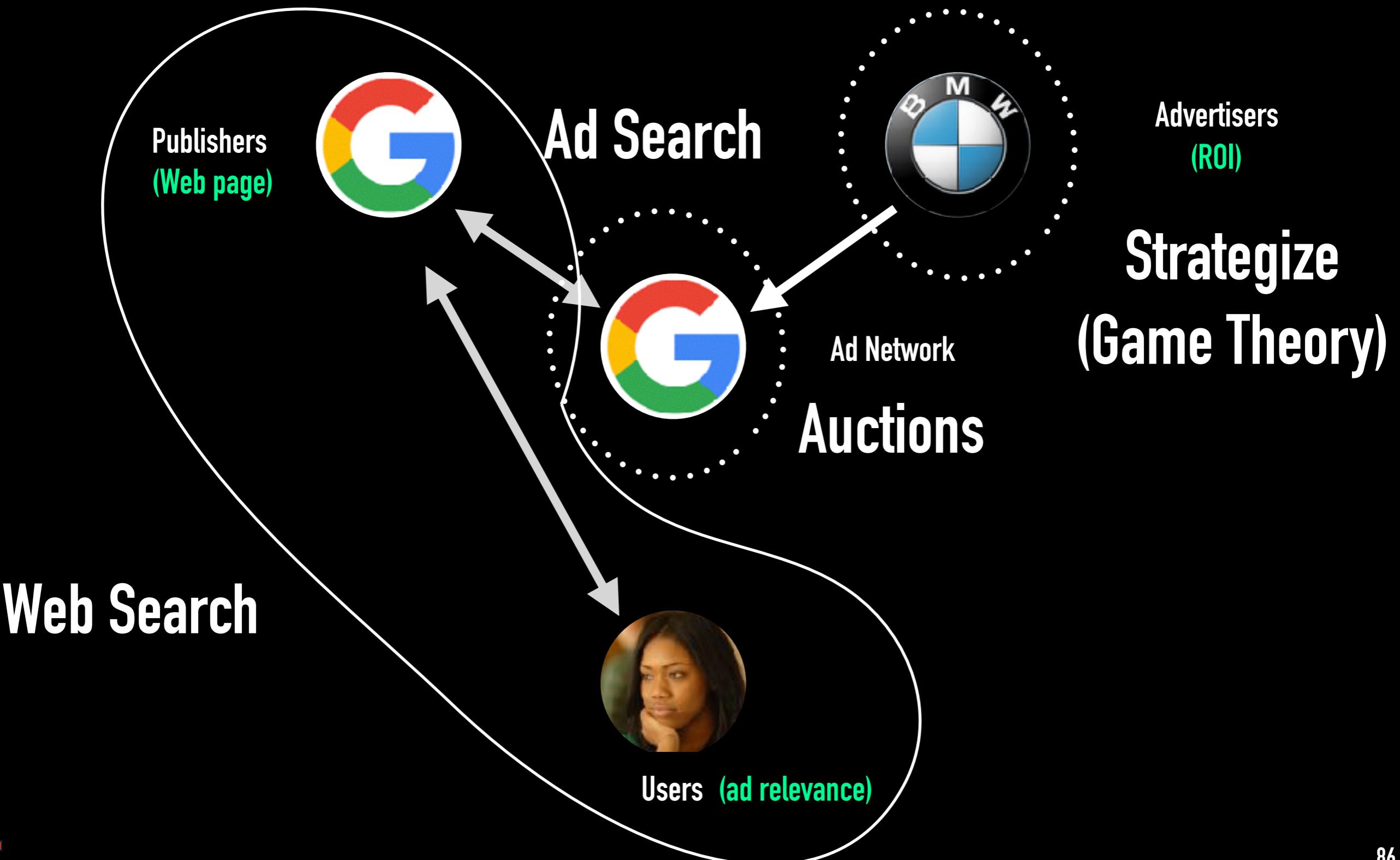
Serving each requests require some CPU amount  
Data usually needs to be in memory  
Per-request cost needs to be lower than the serving cost Low CTR make this a challenging problem

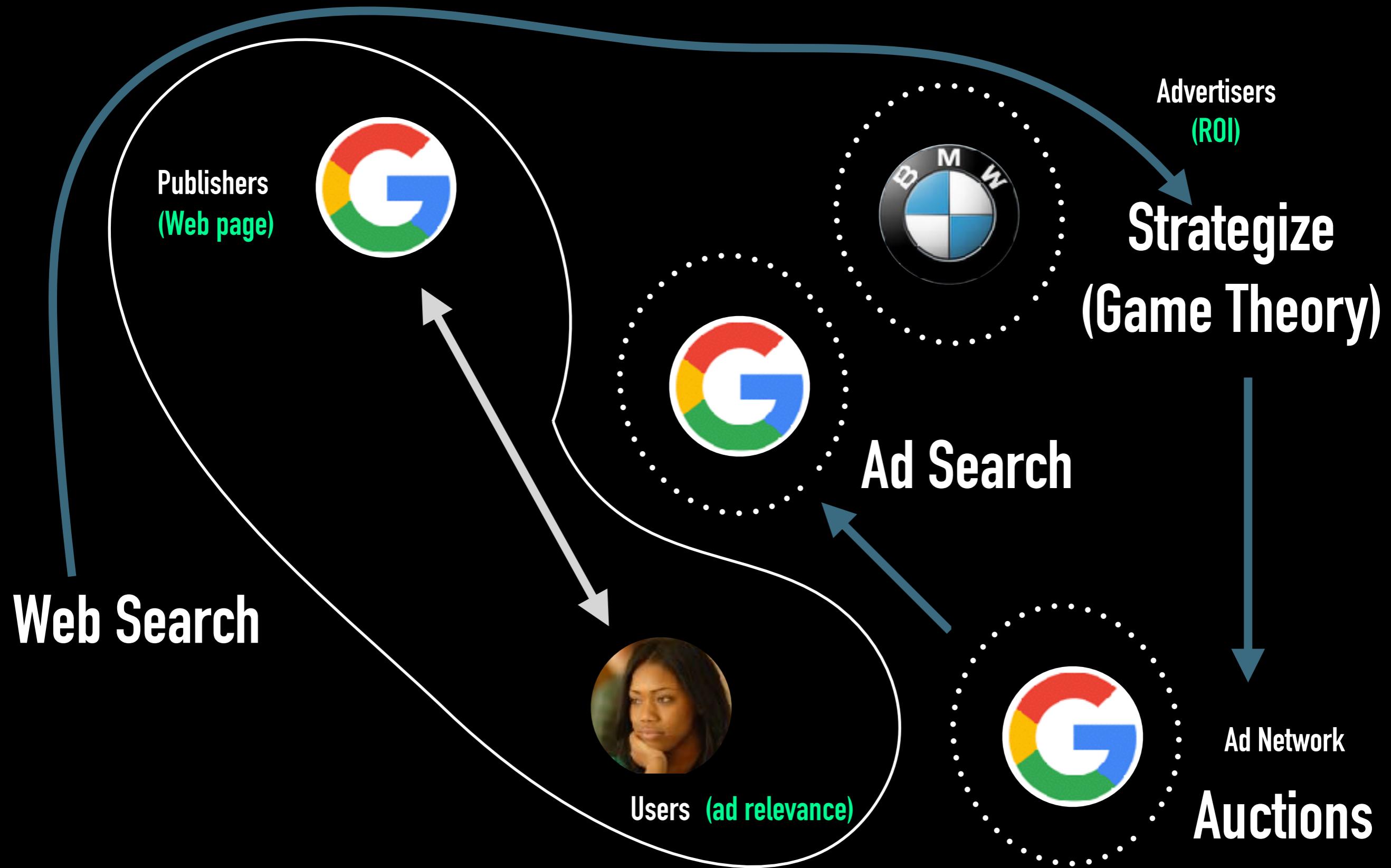
Search Engine perspective

# Three problems



# Sponsored Search





**Goal: Find the "best match" between a given user  
in a given context and a suitable advertisement.**

**Key sub-problems:**

Representation of user/context/ads

Definition of optimization problem

Efficient and effective solution

market design and  
system  
infrastructure are  
also key

Advertising is a form of information.

Adding ads to a context is similar to the  
integration problem of other types of  
information

Finding the “best ad” is often a type of  
information retrieval problem with  
multiple, possibly contradictory utility  
functions

# Summary

The financial scale  
for computational  
advertising is huge

**The landscape of computational  
advertising is changing rapidly  
Tremendous opportunity to innovate**