

Rethinking Online Content Ecosystems through the Lens of Computational Economics

A Tutorial Talk at Sigecom Winter 25 Meeting

Haifeng Xu

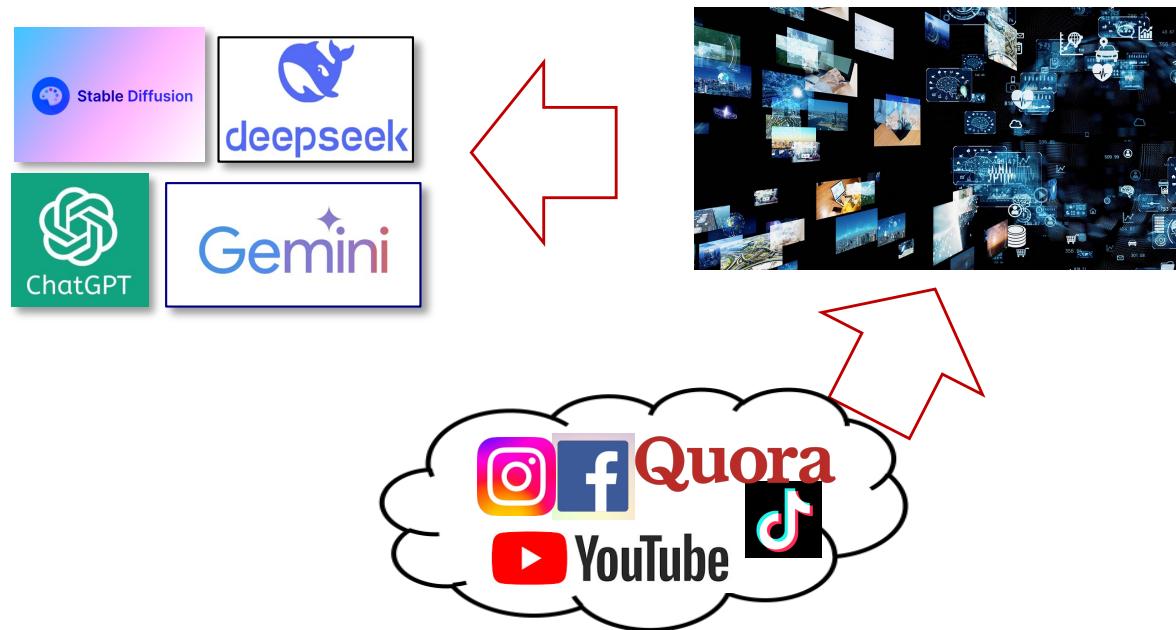
Department of Computer Science
and Data Science Institute

University of Chicago



Content Recommendation System (RS)

- An indispensable component of our life
- Crucial to success of generative AIs (GenAIs)



Classic Research Paradigm in RSSs

System learning/optimization
in
static environments



- ✓ Extensively studied in information retrieval
- ✓ Technology for learning to rank or match preferences is pretty mature (also affirmed by personal experience)



The only
“active” party

Static

Static

But... Still Many Pressing Issues

nature italy

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RESEARCH HIGHLIGHT | 23 February 2021

Measuring magnetism: how social media creates echo chambers

A comparison of sharing platforms shows that users tend to gather in groups whose members think alike, and that polarisation is greater when content feeds cannot be easily tweaked.

[Leggi in italiano](#)



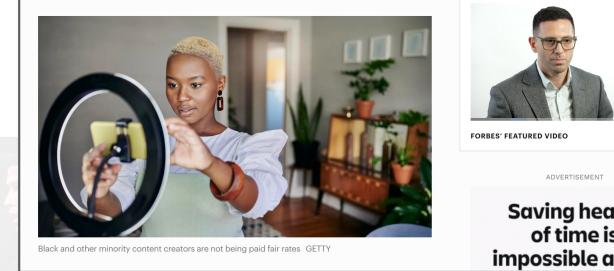
Forbes

Content Creators From Marginalized Backgrounds Are Underpaid, Report Finds

By Kristen Bousquet, Contributor. Kristen Bousquet is an influencer and creator...

Jul 30, 2024, 10:59am EDT

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Black and other minority content creators are not being paid fair rates. GETTY

NOW PLAYING: THREE WAYS SMALL BUSIN



FORBES' FEATURED VIDEO

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Article | [Open access](#) | Published: 09 December 2019

Polarization in social media assists influencers to become more influential: analysis and two inoculation strategies

Ivan Garibay, Alexander V. Mantzaris, Amirarsalan Rajabi & Cameron E. Taylor

Scientific Reports 9, Article number: 18592 (2019) | [Cite this article](#)

17k Accesses | 64 Altmetric | [Metrics](#)

Google

Cultural homogenization social media reddit

All Forums Images News Videos Shopping Web More

Reddit - r/nosurf
10+ comments · 1 year ago ·

Social media and unification of culture : r/nosurf
There's the simultaneous homogenization and fracturing of culture going on. On one hand, cultures are bleeding into each other. Trends ...

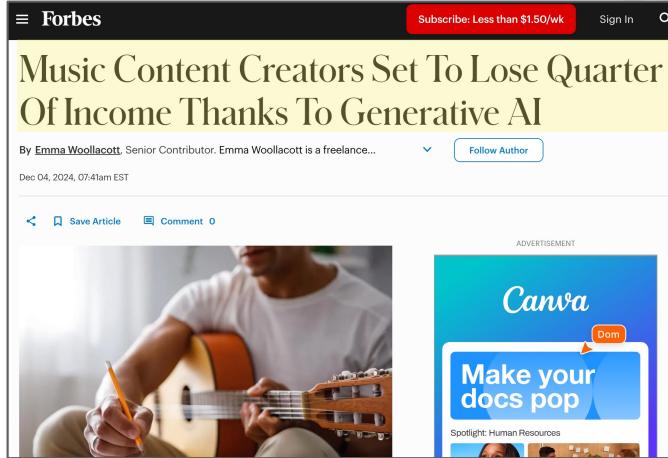
Reddit - r/linguistics
70+ comments · 5 years ago ·

Is the internet leading to homogenization of different national dialects? : r/linguistics
Is the internet leading to homogenization of different national dialects of languages? who's lived in Mexico for seven years now ...
71 answers · Top answer: William Labov's acoustic studies show the opposite for US accents

Reddit - r/nosurf
50+ comments · 2 months ago ·

The Internet Is Making Everyone And Everything The Same : r/nosurf
He talks, among other things, about how culture is becoming homogenized globally, a "global melting pot". His famous example is what he ...

More Issues Arise with AI-Generated Content (AIGC)



Forbes

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Music Content Creators Set To Lose Quarter Of Income Thanks To Generative AI

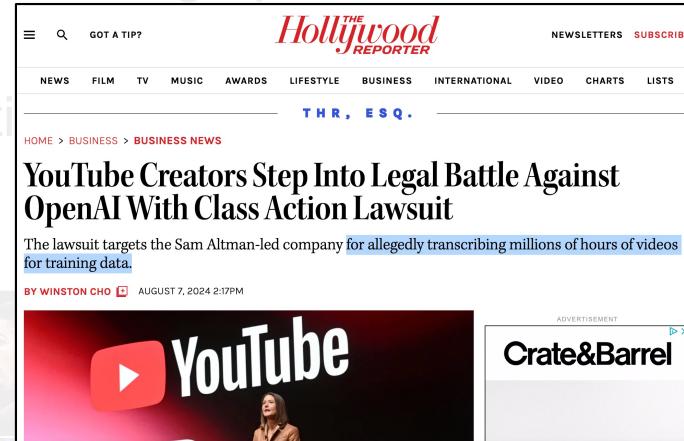
By Emma Woollacott, Senior Contributor. Emma Woollacott is a freelance... Dec 04, 2024, 07:41am EST

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A person playing a guitar.

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GOT A TIP?

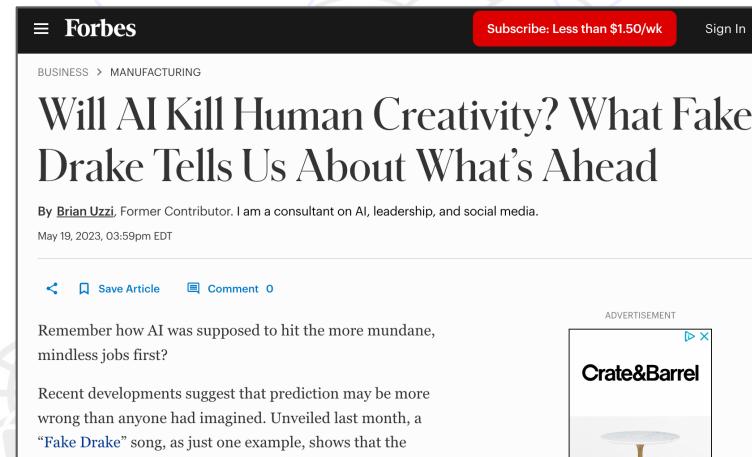
YouTube Creators Step Into Legal Battle Against OpenAI With Class Action Lawsuit

The lawsuit targets the Sam Altman-led company for allegedly transcribing millions of hours of videos for training data.

BY WINSTON CHO AUGUST 7, 2024 2:17PM

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BUSINESS > MANUFACTURING

Will AI Kill Human Creativity? What "Fake Drake" Tells Us About What's Ahead

By Brian Uzzi, Former Contributor. I am a consultant on AI, leadership, and social media. May 19, 2023, 03:59pm EDT

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Remember how AI was supposed to hit the more mundane, mindless jobs first?

Recent developments suggest that prediction may be more wrong than anyone had imagined. Unveiled last month, a "Fake Drake" song, as just one example, shows that the

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Why?

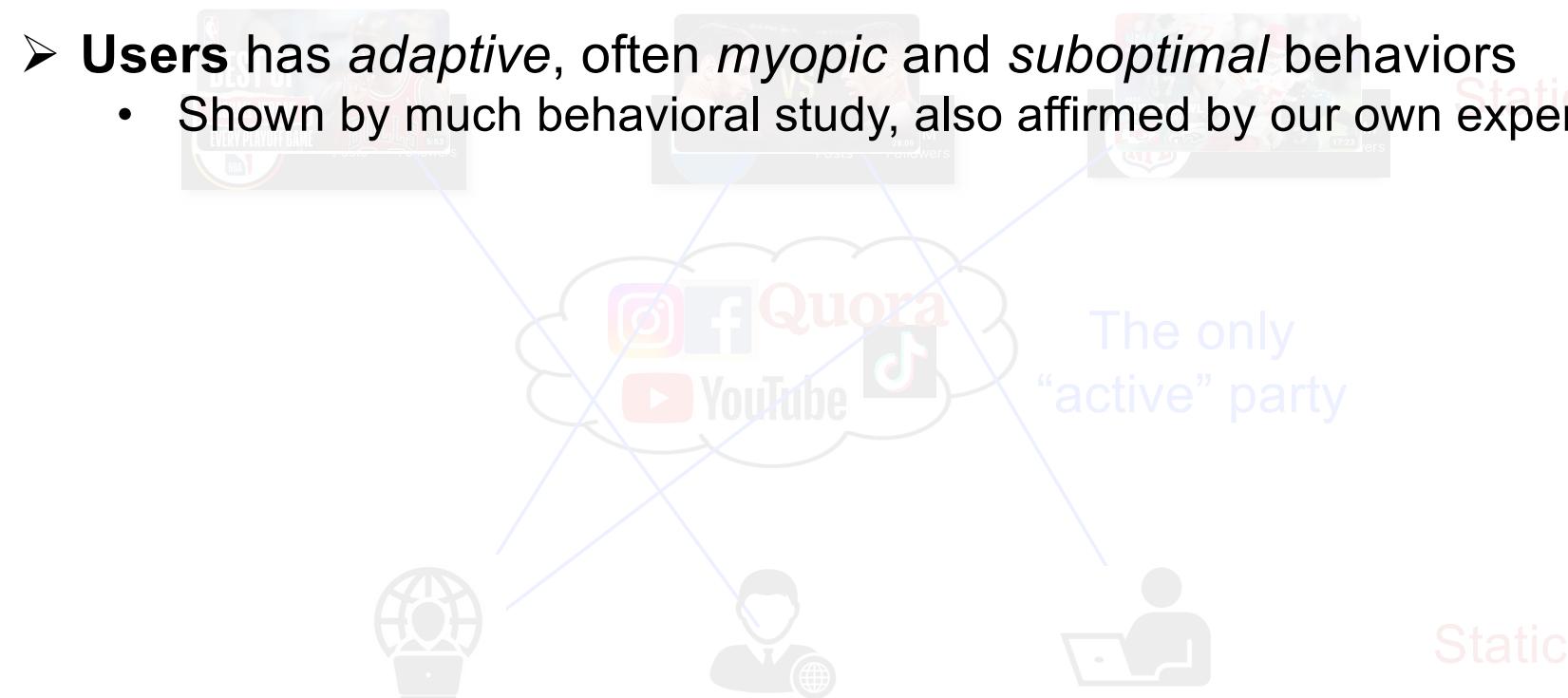
Pure Learning Overlooks Creators' and Users' Autonomy

➤ **Creators** respond to incentives

- E.g., Youtubers create longer videos when they are rewarded by view duration [MC'23])
- AIGC significantly reshapes creators' incentives

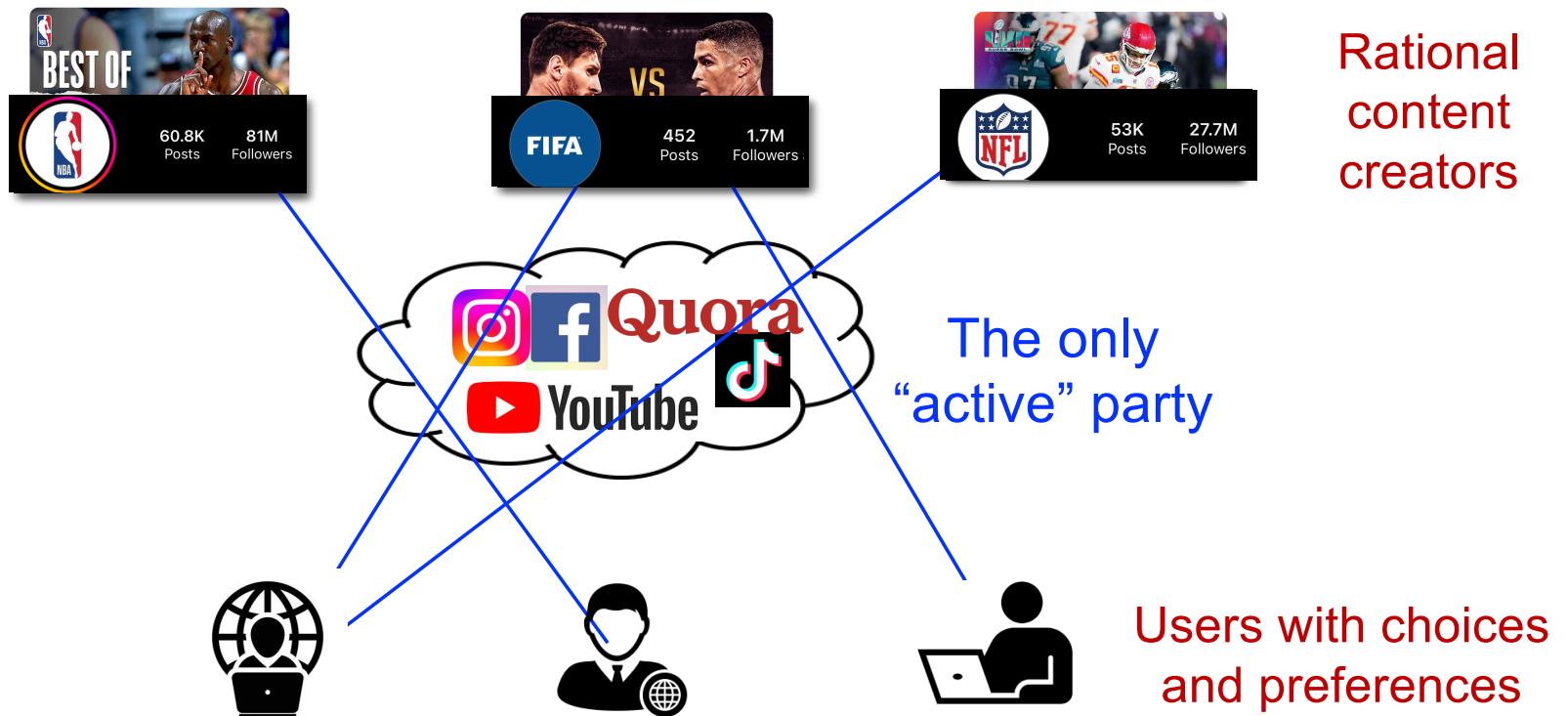
➤ **Users** has *adaptive*, often *myopic* and *suboptimal* behaviors

- Shown by much behavioral study, also affirmed by our own experience

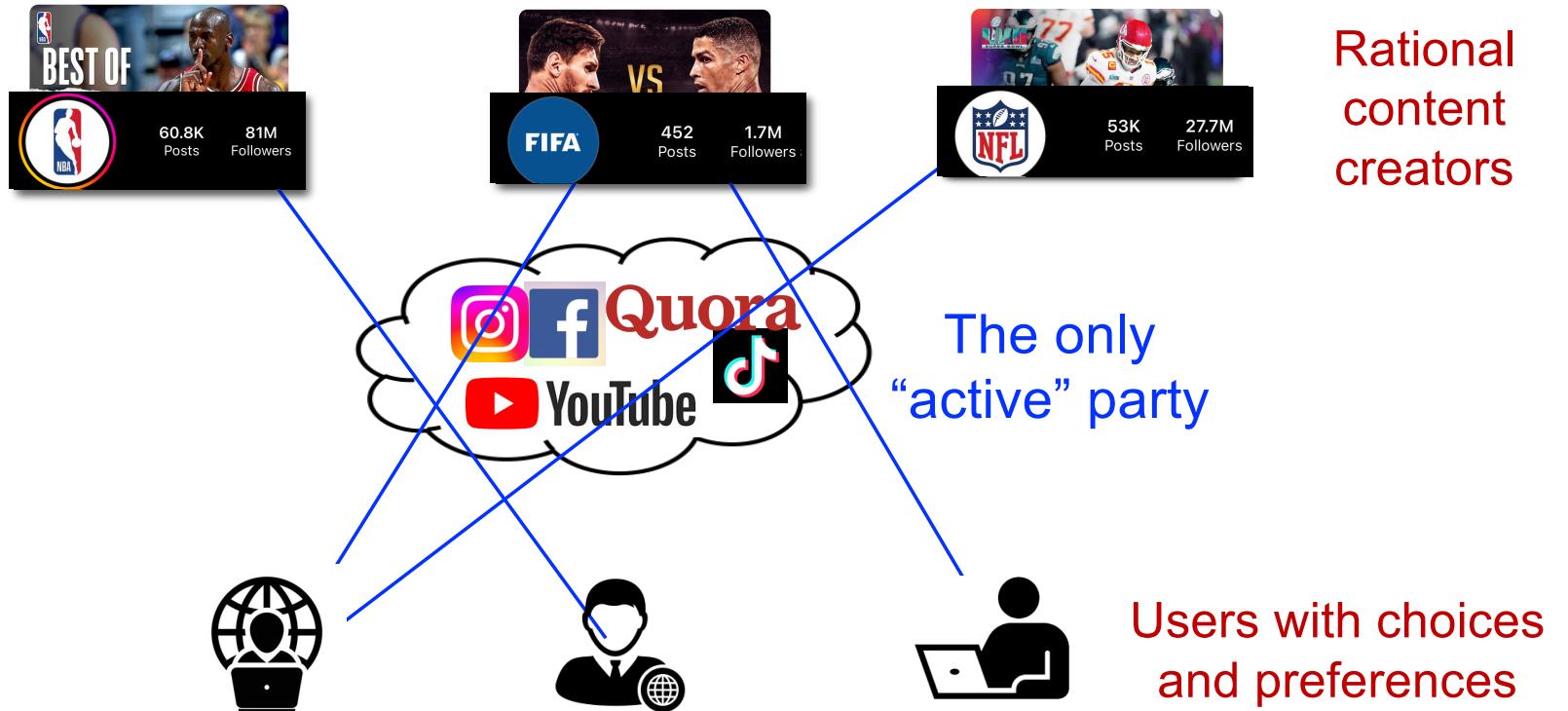


System optimization in static environments

Rethinking classic RS paradigm....



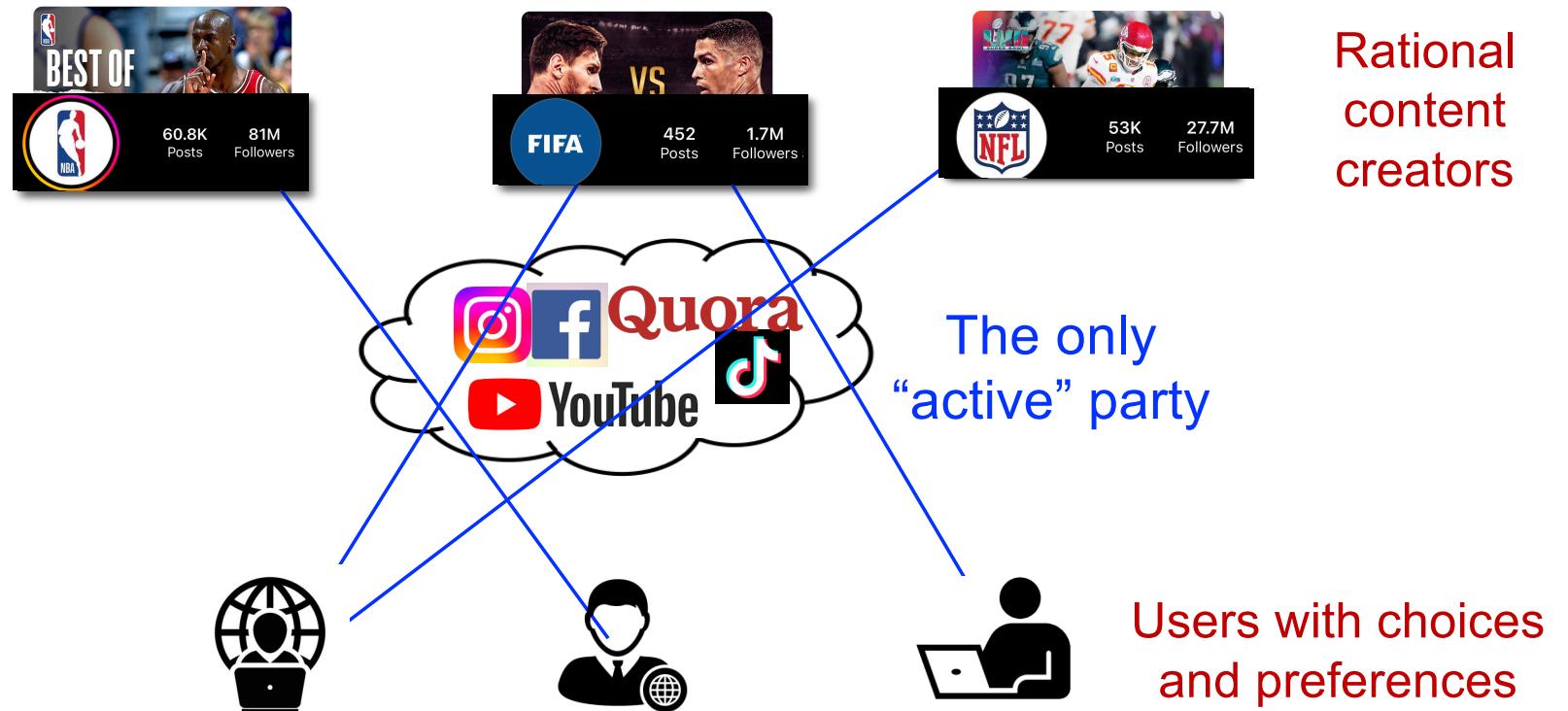
Multi-agent interactions ~~System optimization~~ Rethinking classic RS paradigm.... ~~in static environments~~



Remainder of this talk will survey recent works that

- Model incentives and agency in content ecosystems
- Study equilibria, incentive mechanisms, and impact of AIGC

Multi-agent interactions ~~System optimization~~ Rethinking classic RS paradigm.... ~~in static environments~~

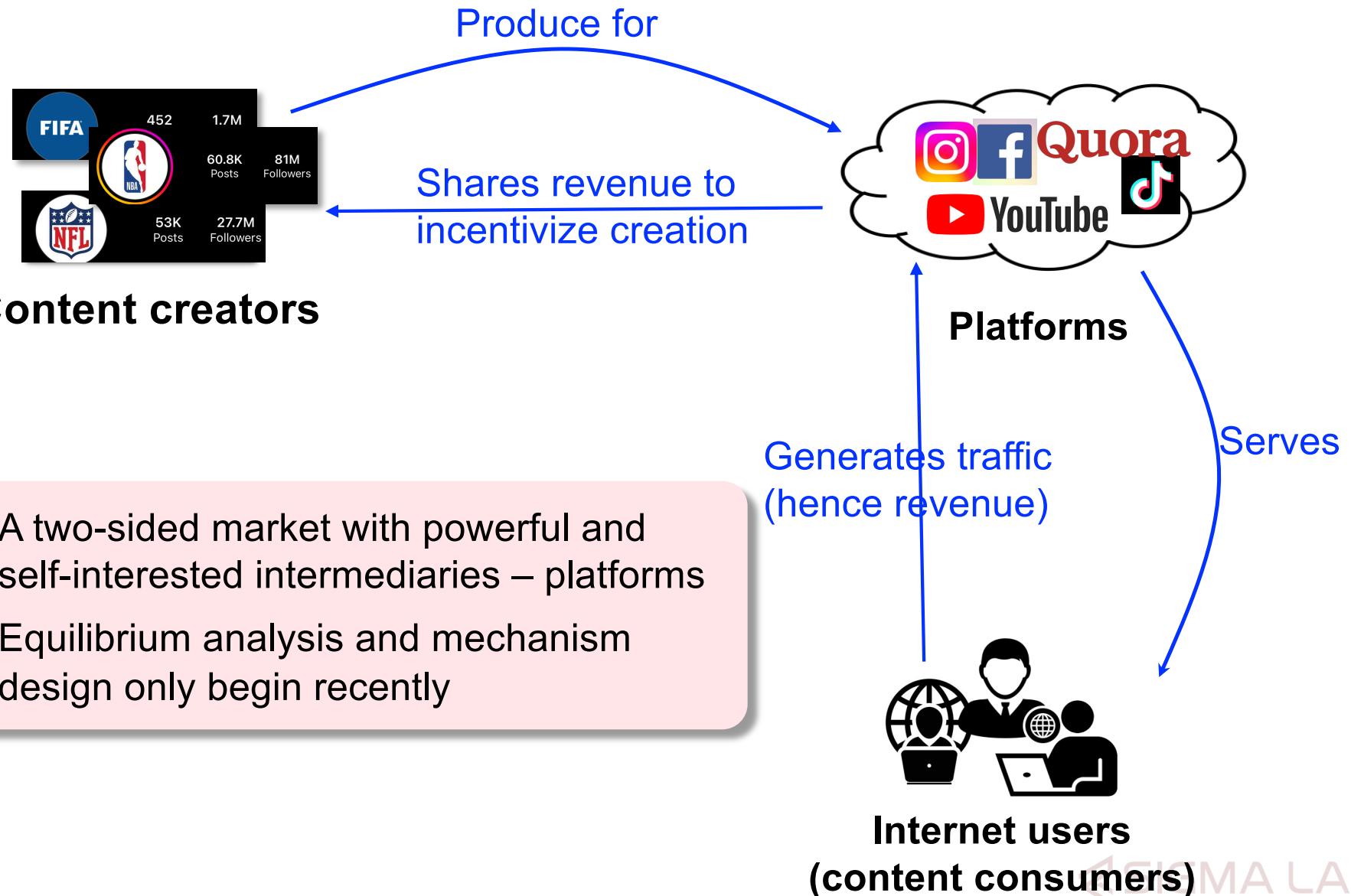


Outline

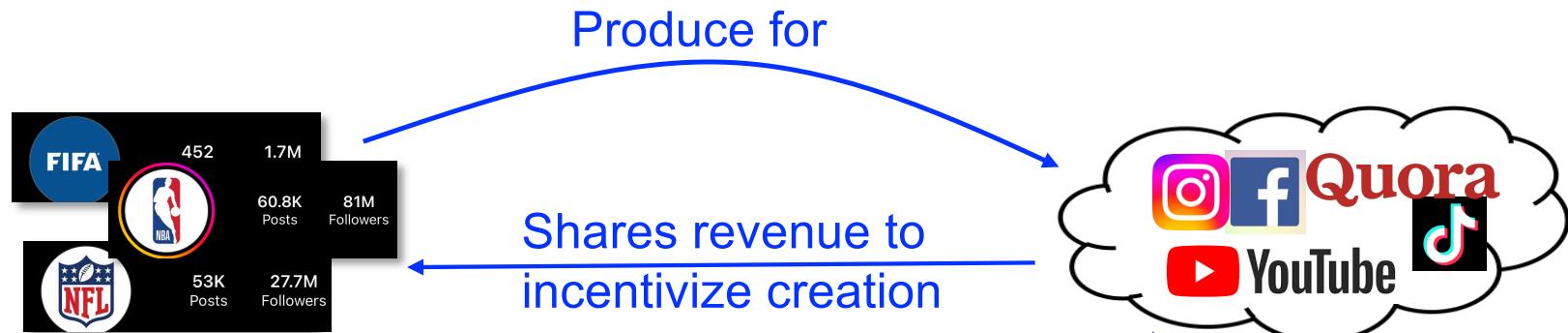
- **Part I: Diagnosing and Optimizing Existing Content Ecosystems**

- **Part II: How Does AIGC Transform Future Content Ecosystems**

A Game with Three Types of Players



Recent Advances: Supply Side



Content creators

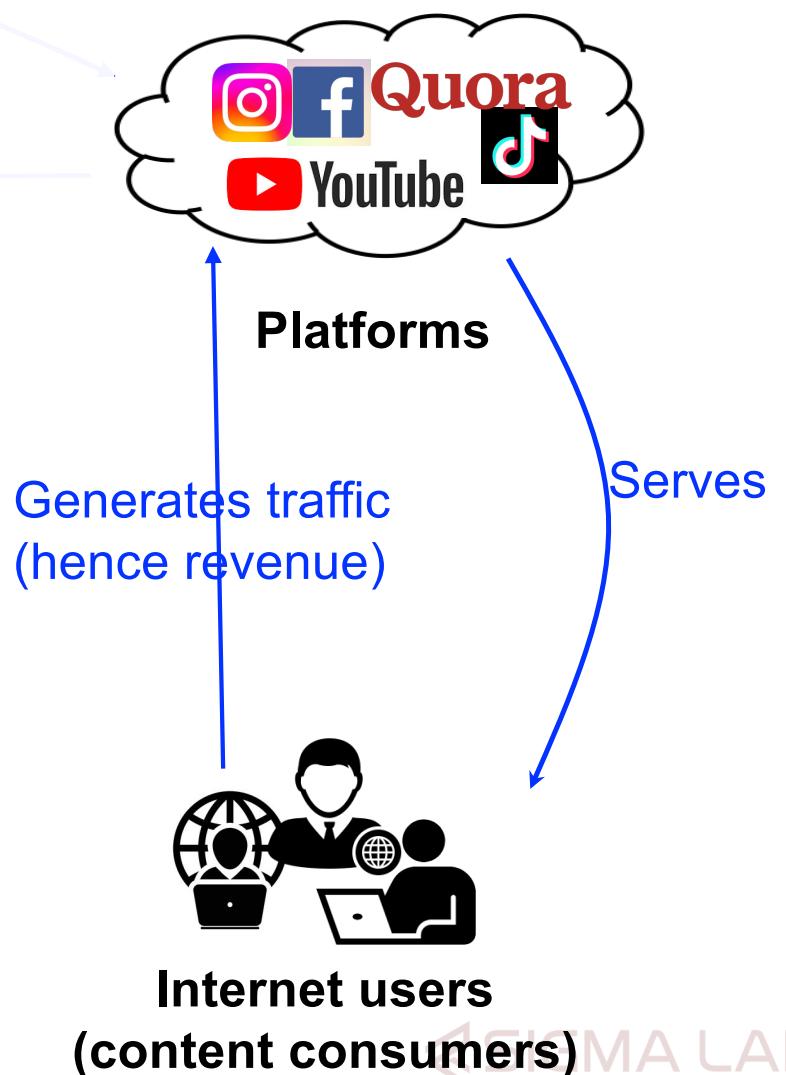
- [\[Ben-Porat and Tennenholz, NeurIPS'18\]](#) and [\[Ben-Porat et al., NeurIPS'20\]](#) are the first to consider creator competition and platform mediation
- [\[Mladenov et al. ICML'20\]](#) studies system's matching mechanism, accounting for creator incentives
- [\[Jagadeesan et al, NeurIPS'23\]](#) characterizes content distributions at equilibrium

Recent Advances: Consumption Side

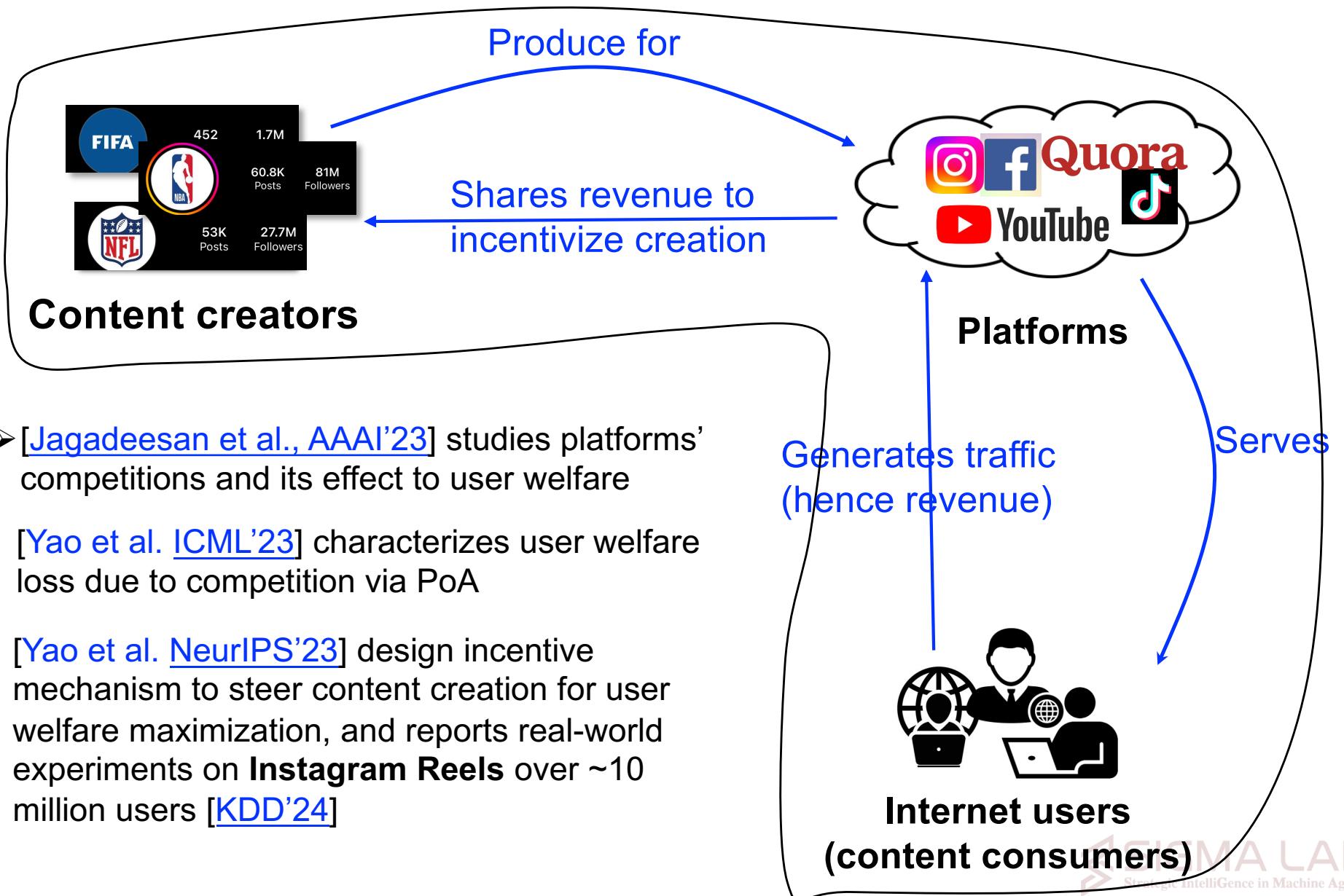
Less studied; research mostly focuses on improving recommendation efficiency via “behavior-aware” system learning

- [Kleinberg et al., MS’23] considers platform’s learning of user preferences and argues that sub-optimality comes from human’s irrational behaviors
- [Yao et al., ICML’22] designs platform’s algorithms to learn from explorative users

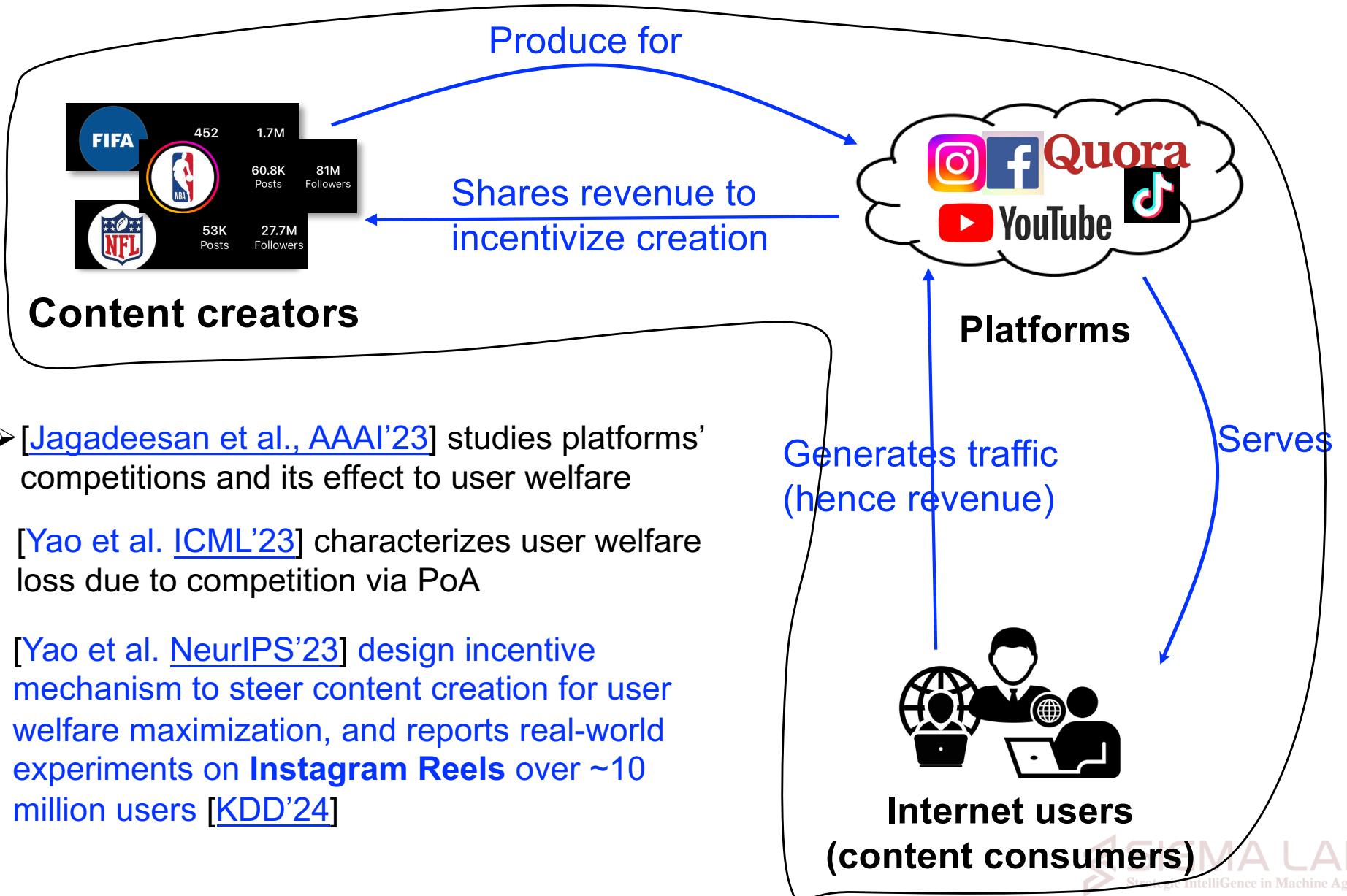
Produce for



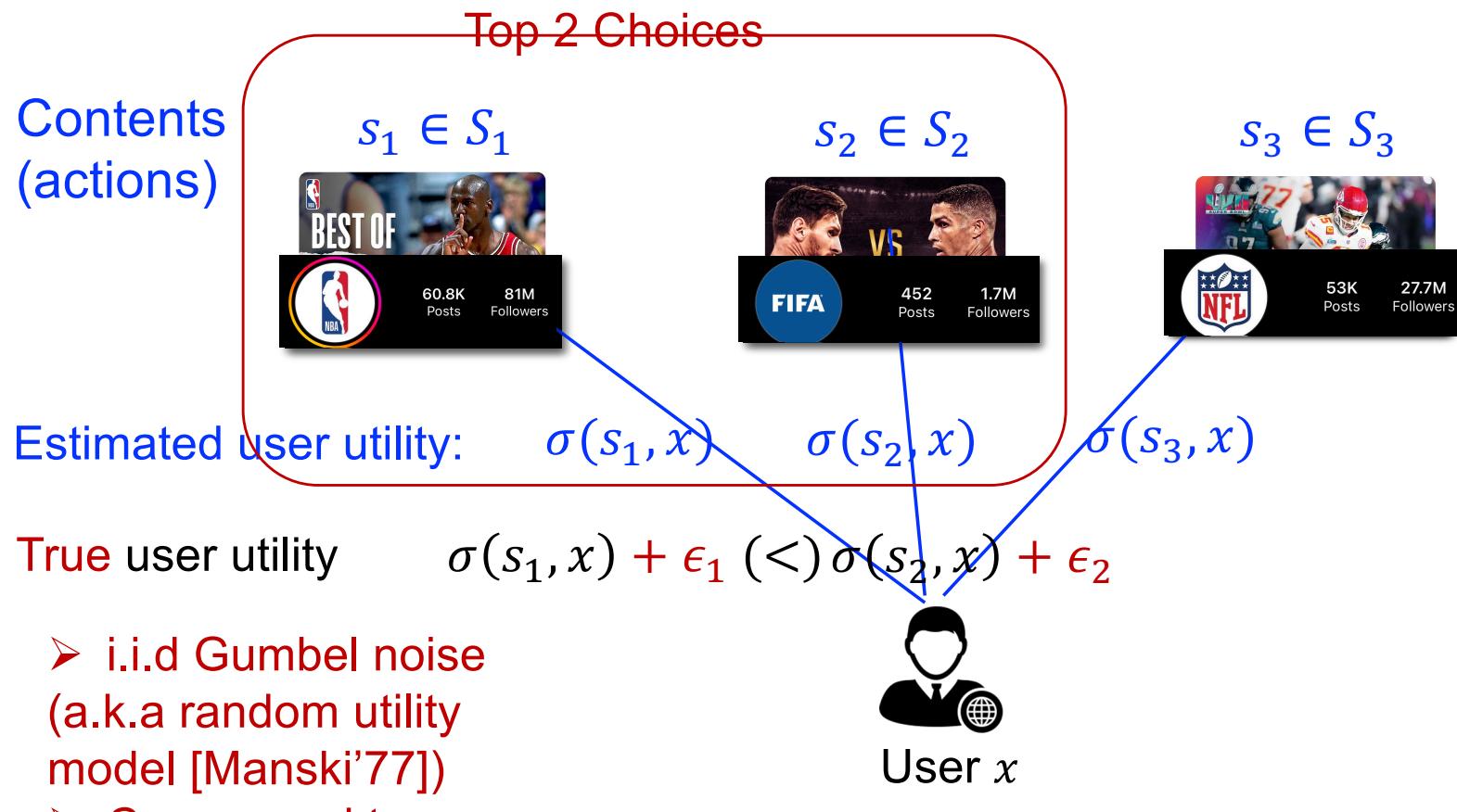
Recent Advances: Ecosystem Perspective



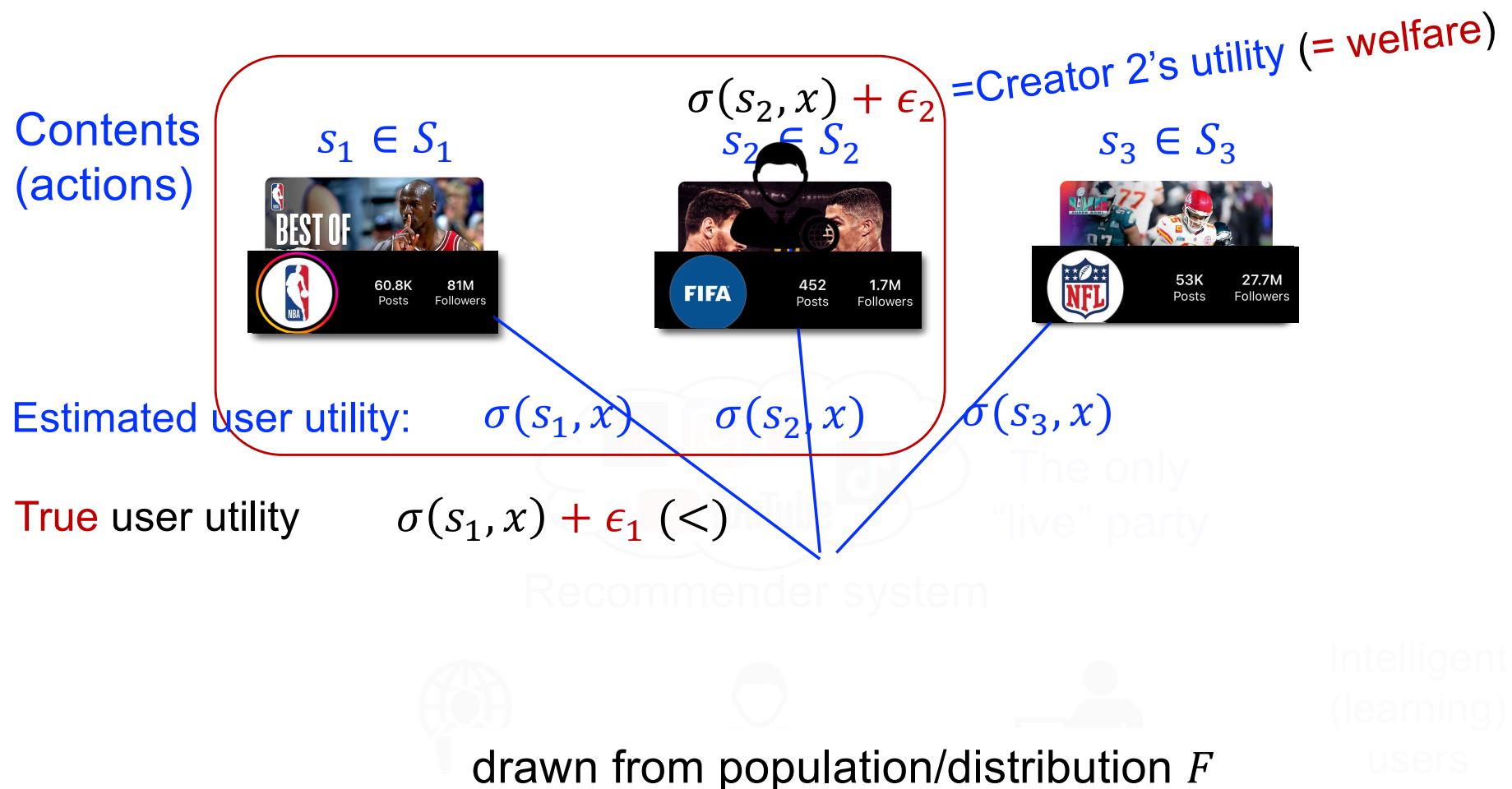
Recent Advances: Ecosystem Perspective



Modeling the Content Creation Competition (C3)



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- Content creator's objective: (1) maximize traffic (i.e., attracted users), minus producing cost

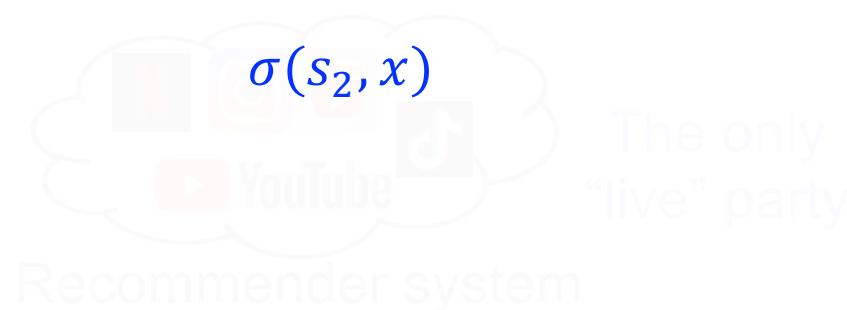
$$\mathbb{E}_{x \sim F} [\mathbb{I}(x \text{ visits creator 2})] - c_2(s_2)$$

$$\sigma(s_2, x) + \epsilon_2 \quad \text{= Creator 2's utility (= welfare)}$$

$s_2 \in S_2$



$$\sigma(s_2, x)$$



Intelligent
(learning)
users



Modeling the Content Creation Competition (C3)

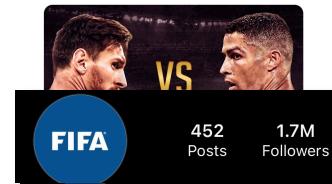
- Content creator's objective: (1) maximize traffic (i.e., attracted users), minus producing cost or (2) maximize welfare/happiness of their traffic

$$\mathbb{E}_{x \sim F} [\mathbb{I}(x \text{ visits creator 2}) \cdot (\sigma(s_2, x) + \epsilon_2)] - c_2(s_2)$$

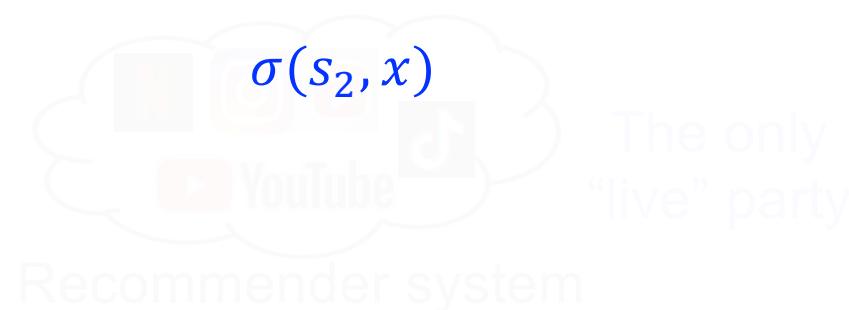
Rewards from platform



$\sigma(s_2, x) + \epsilon_2$ =Creator 2's utility (= welfare)
 $s_2 \in S_2$



$\sigma(s_2, x)$



Intelligent
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users

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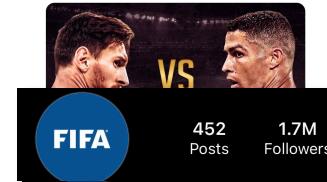
Rewards from platform



$$\sigma(s_2, x) + \epsilon_2$$

=Creator 2's utility (= welfare)

$$s_2 \in S_2$$



$$\sigma(s_2, x)$$

- Platform cares about system efficiency – i.e. total welfare

$$\sum_i U(\text{creator } i) + \sum_x [U(\text{user } x)]$$

This modeling structure is the backbone of many previously mentioned works, though details could be different

The Inefficiency of Rewarding Only Traffic or Welfare

Content creator's objective: (1) maximize traffic (i.e., attracted users), minus producing cost or (2) maximize welfare/happiness of their traffic

$$\mathbb{E}_{x \sim F} [\mathbb{I}(x \text{ visits creator 2}) \cdot (\sigma(s_2, x) + \epsilon_2)] - c_2(s_2)$$

- Can have large price of anarchy (though often smaller than 2) [Yao et al., ICML'23]

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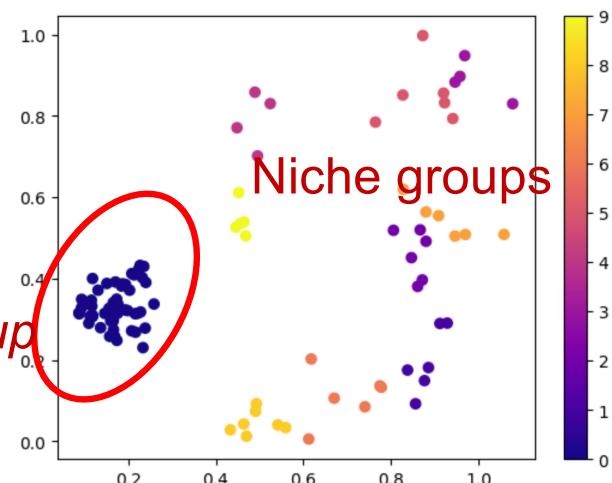
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Inefficiency is due to “tragedy of commons” type of phenomenon

*A dominating
trendy user group*



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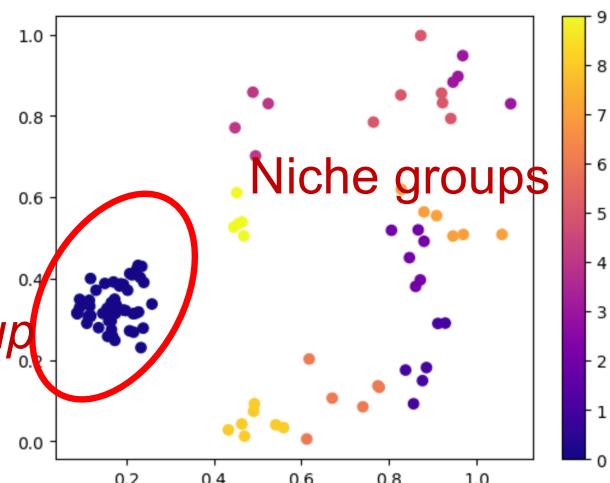
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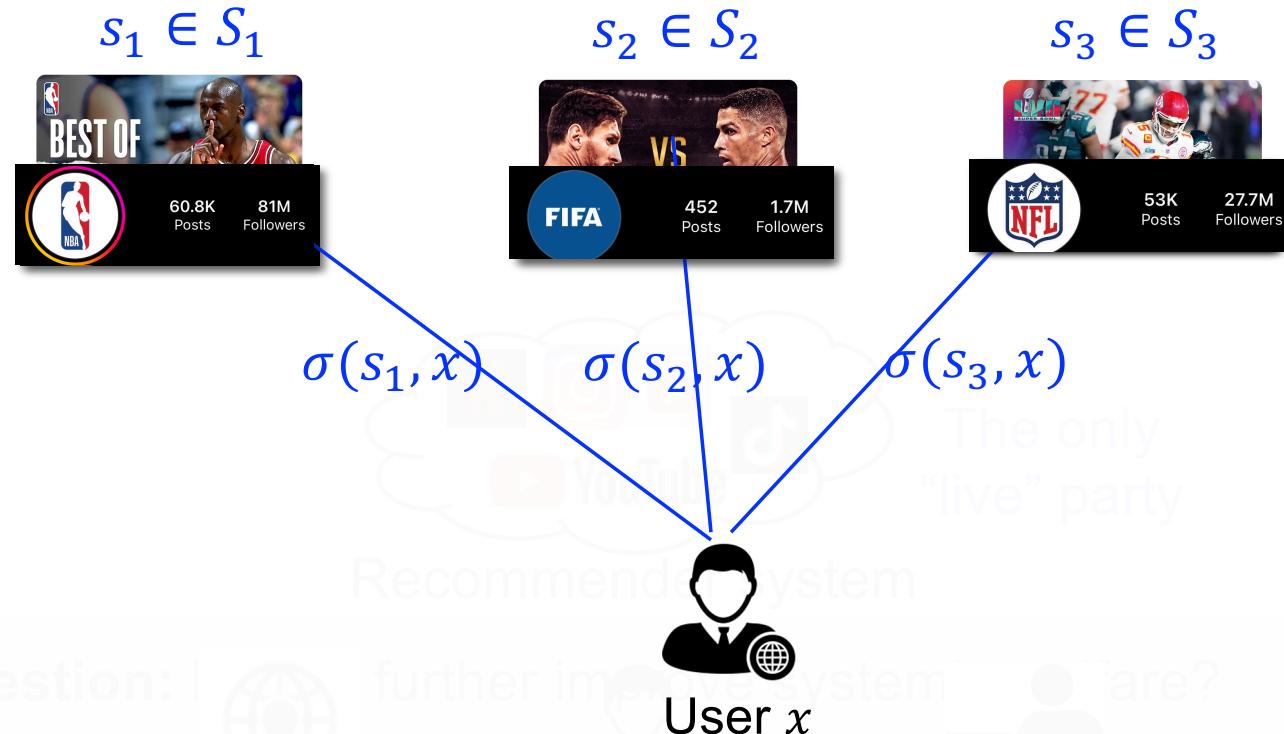
- Can have large price of anarchy (though often smaller than 2) [Yao et al., ICML'23]
- In fact, if creator reward mechanism satisfies certain monotone properties, it can never be welfare-maximizing [Yao et al., NeurIPS'23]

Inefficiency is due to “tragedy of commons” type of phenomenon

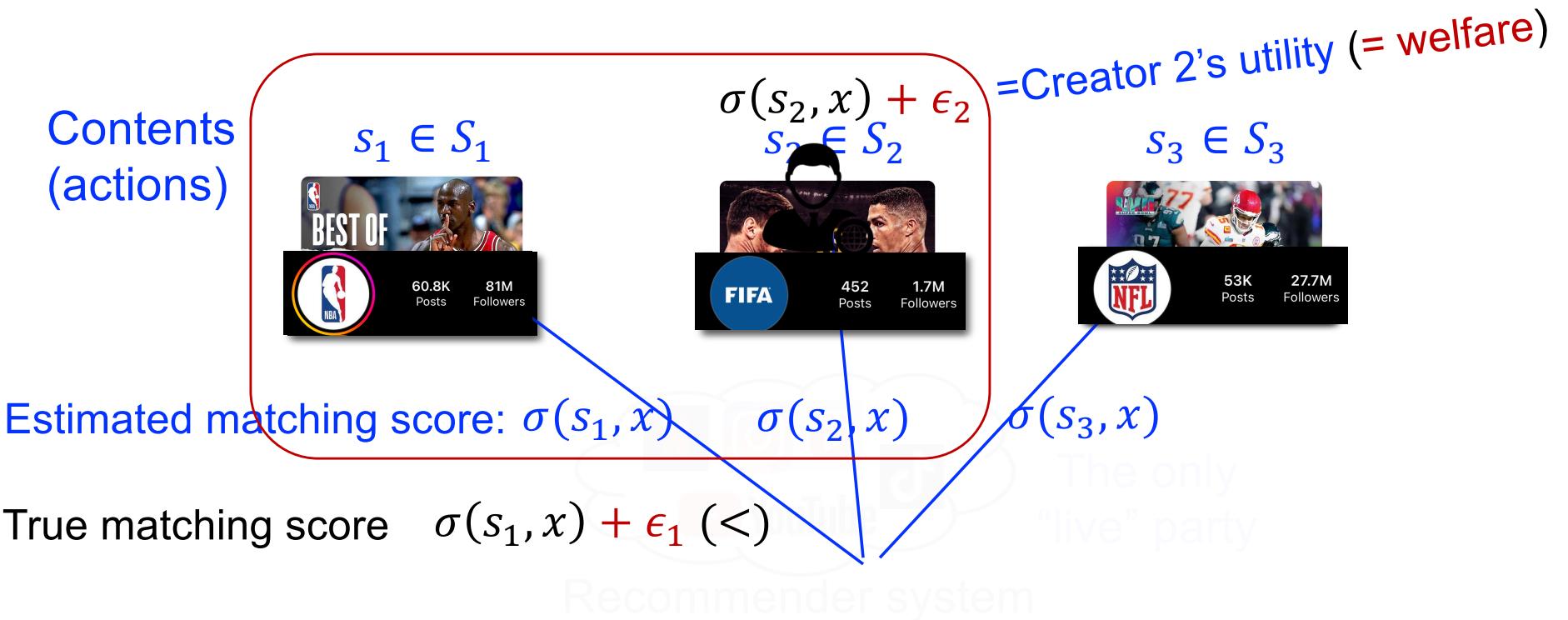
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Mechanism Design to Incentivize Content Creation

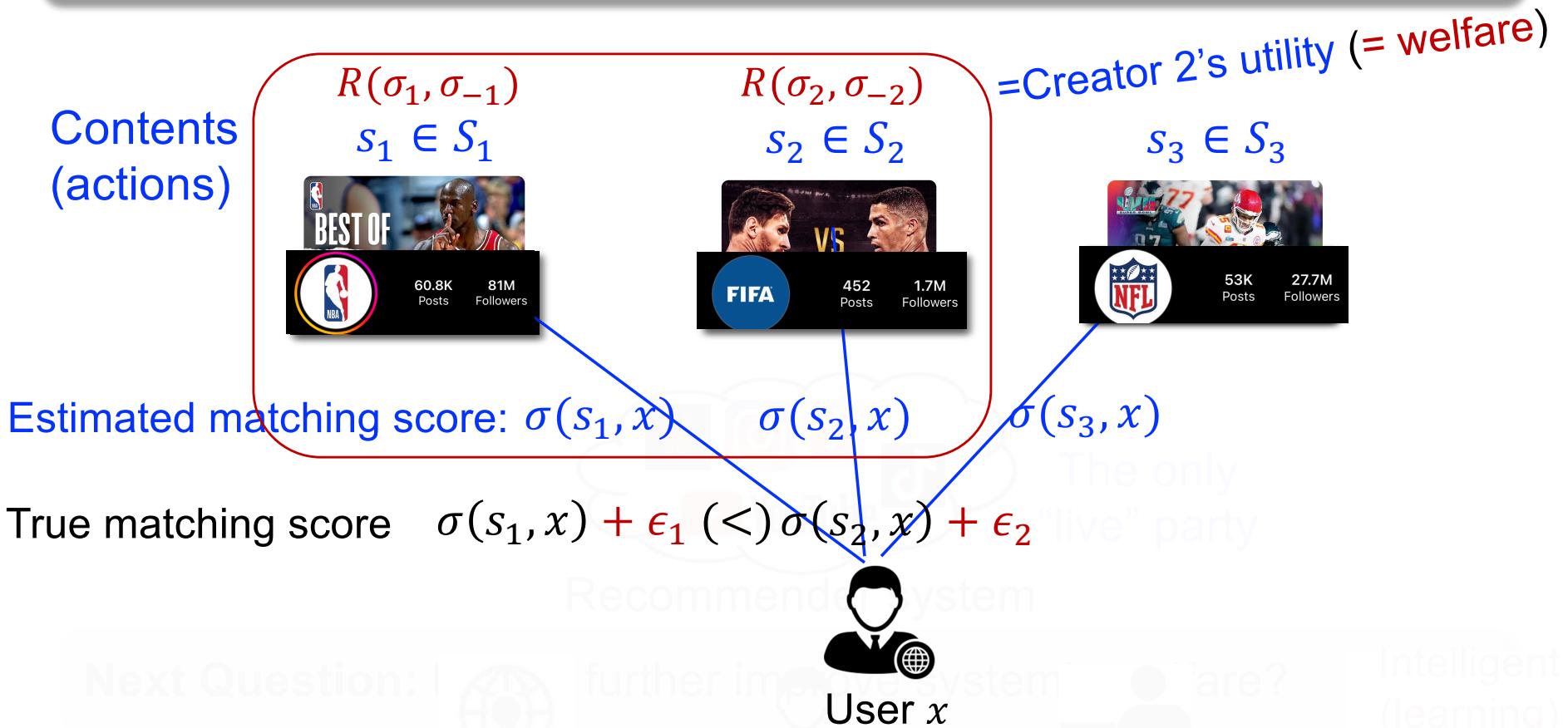


Mechanism Design to Incentivize Content Creation



Mechanism Design to Incentivize Content Creation

Q: Can we design/optimize the reward values R to “steer”/incentivize creators’ collective behaviors towards better total welfare?

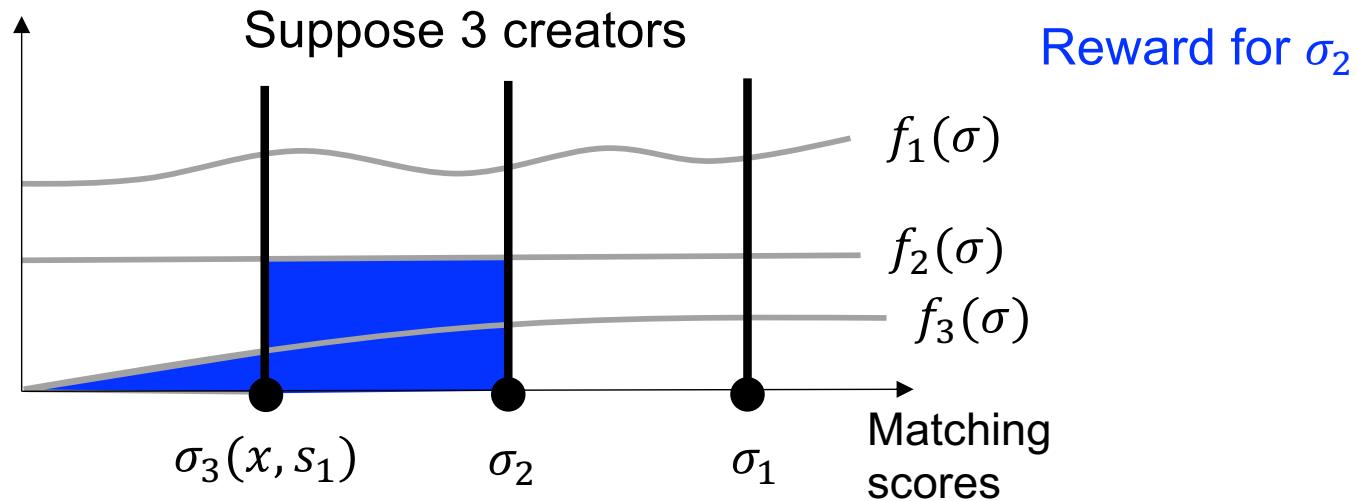


Mechanism Design to Incentivize Content Creation

[Yao et al.'23] develops a new mechanism that introduces more competition for congested topics, and achieves optimal welfare at equilibrium

Core idea: reward based on how much a creator is better than the next

- Mechanism is fully described by these functions
- Reward = area of ■■■■■

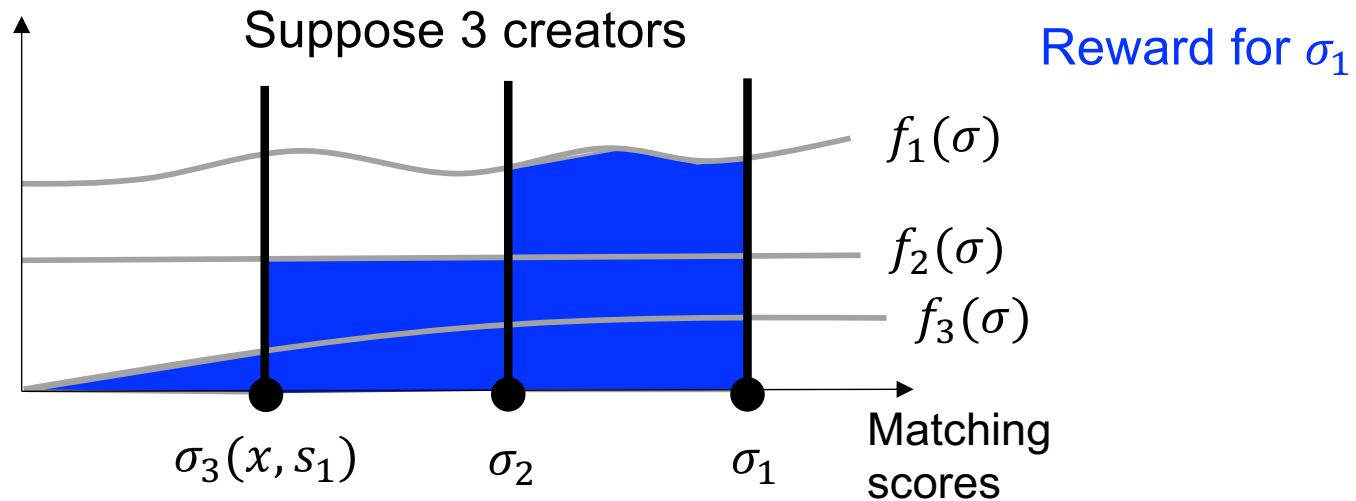


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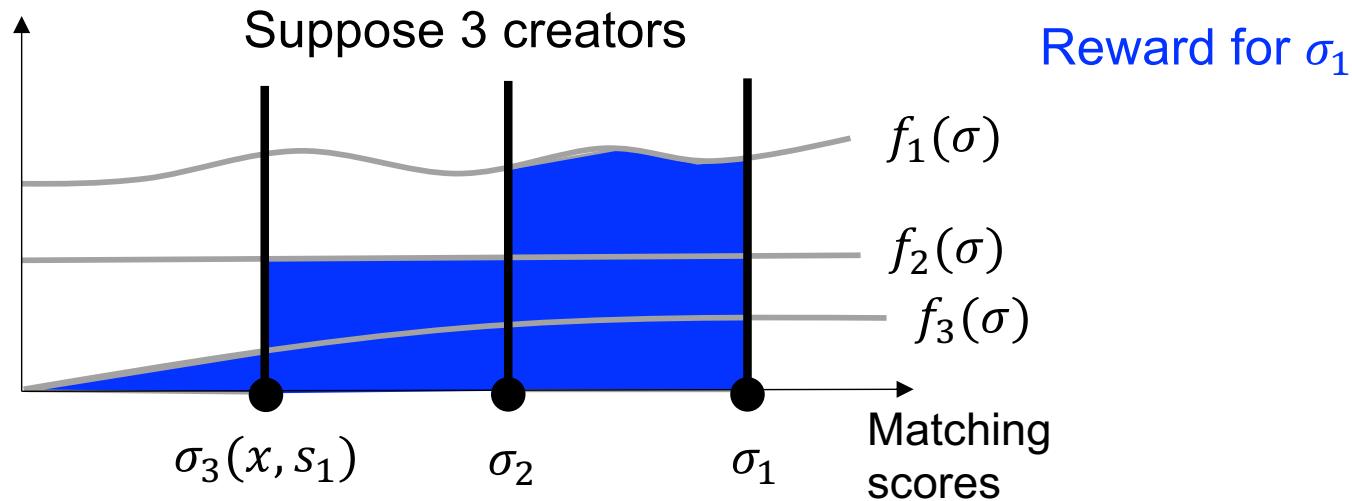


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- ✓ σ_1 's reward decreases when σ_2 becomes better (i.e., competition reduces rewards)

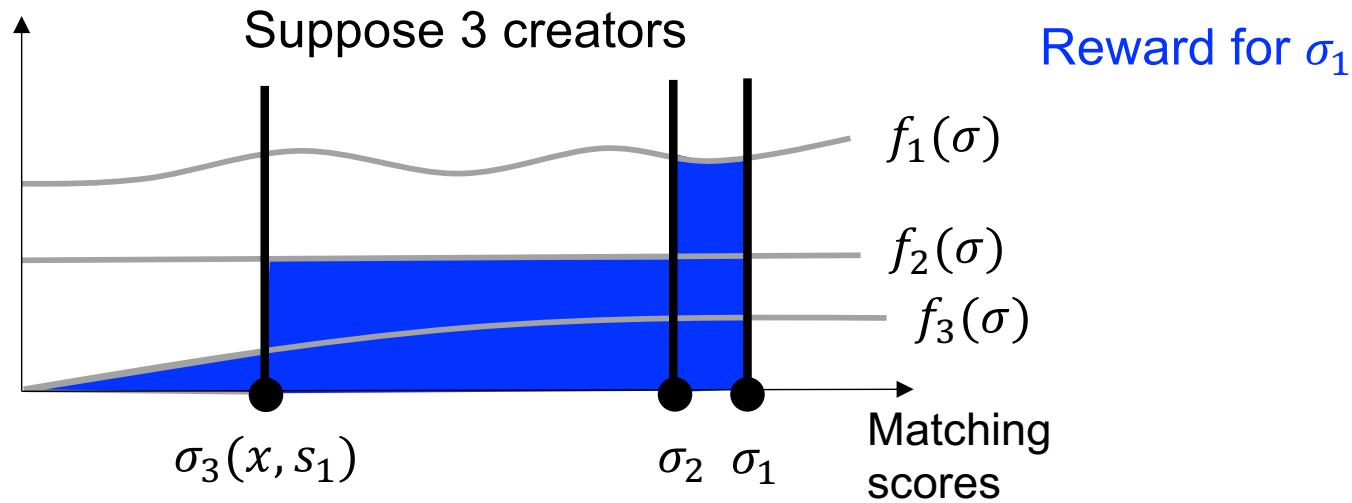


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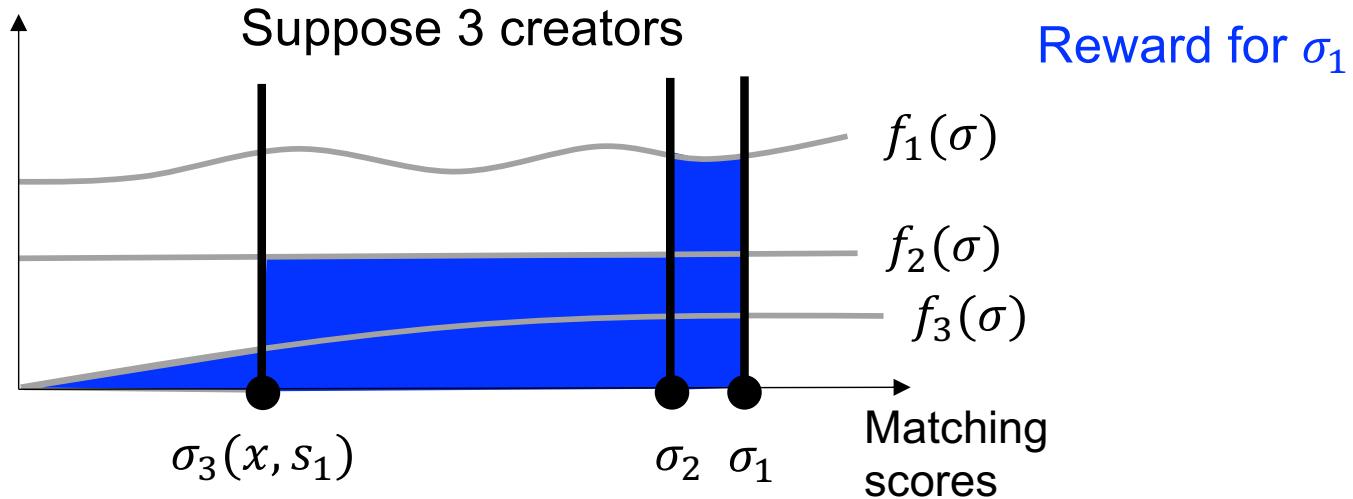
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- ✓ Naturally handles top- K selection by setting $f_{K+1} = \dots = f_n = 0$



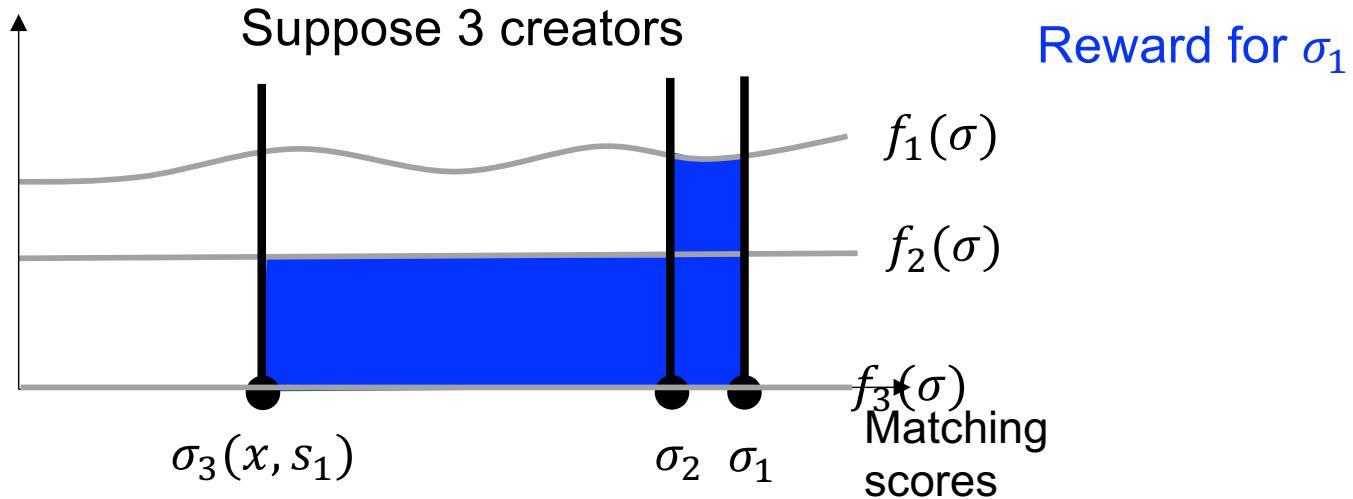
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Mechanism Design to Incentivize Content Creation

[Yao et al.'23] develops a new mechanism that introduces more competition for congested topics, and achieves optimal welfare at equilibrium

Theorem (informal).

1. Previous mechanism always induces a *potential game* among creators;
2. There is a choice of f_1, f_2, \dots, f_n that make the potential function precisely the system's welfare function (\Rightarrow welfare is maximized at a pure Nash)

- A variant of this mechanism was tested on Instagram Reels, with results reported in [Yao et al, KDD'24]
- A “separated world” with ~10 millions users/creators
 - A/B testing for 8 weeks

 Meta



Real-world Experimental Results from A/B Test

User Groups	1-5	6-20	21-74	75+	TOTAL
Like-Through-Rate	+0.43%	+1.40%	+0.75%	+1.36%	+1.13%
Impression	+2.64%	+0.62%	+1.42%	+0.11%	+0.76%

Nice side effects

- ✓ 3.7% increase in diversity of user impression
- ✓ Increased diversity of user consumption
 - 0.71 increase on average number of consumed topic per user

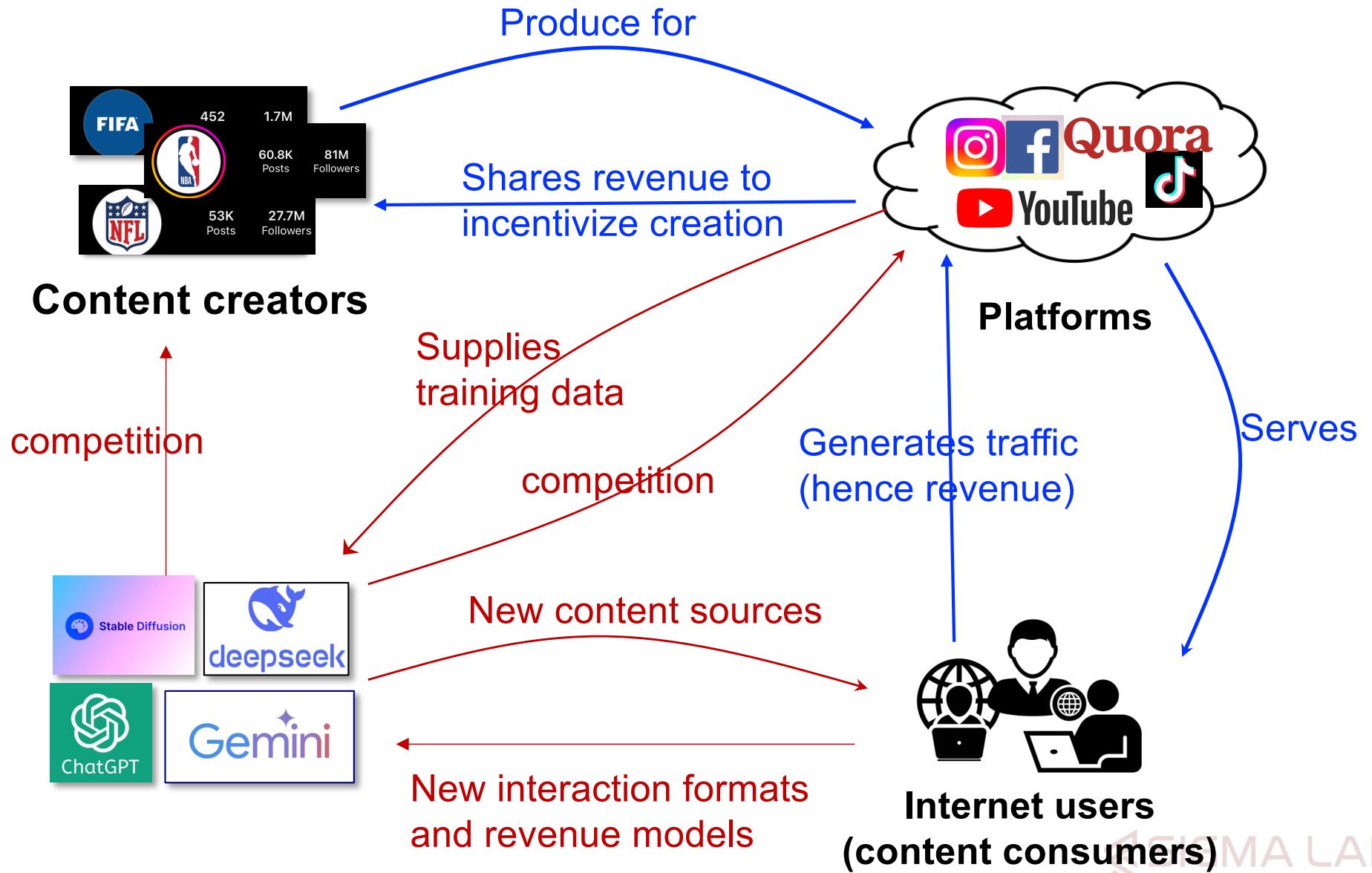
These improvements are significant even compared to launched methods

Outline

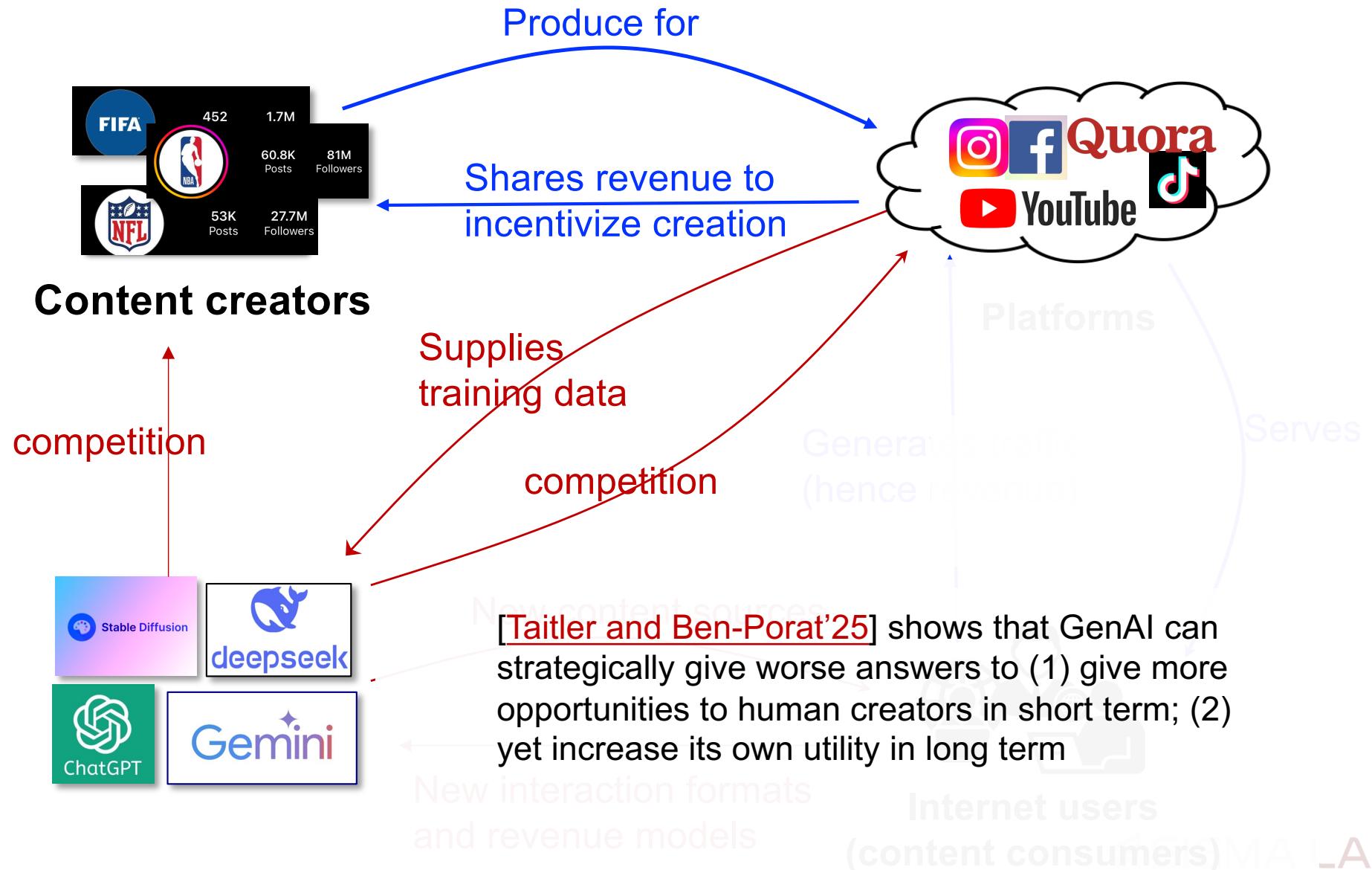
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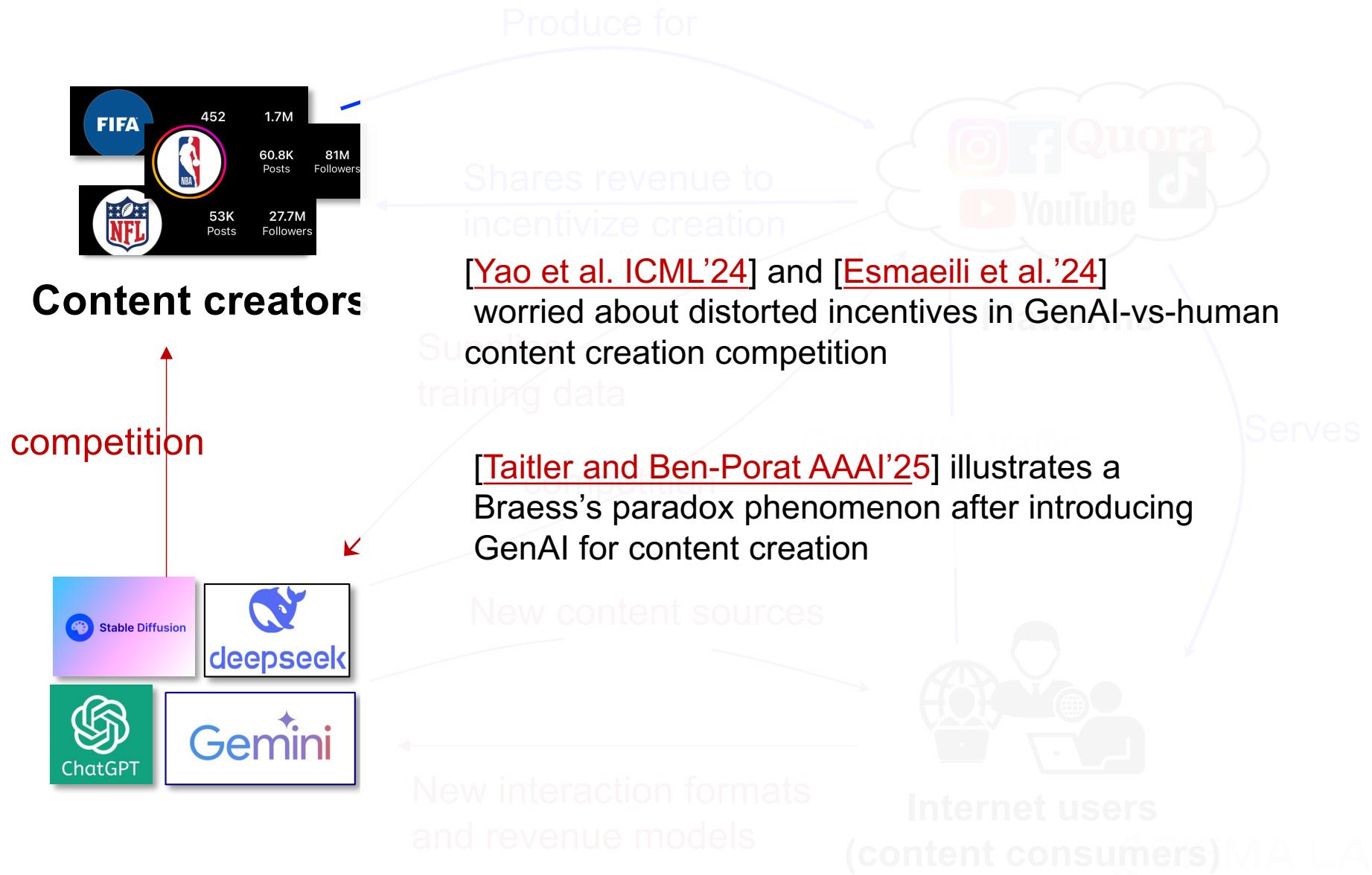
Generative AI as a Forth Player Type



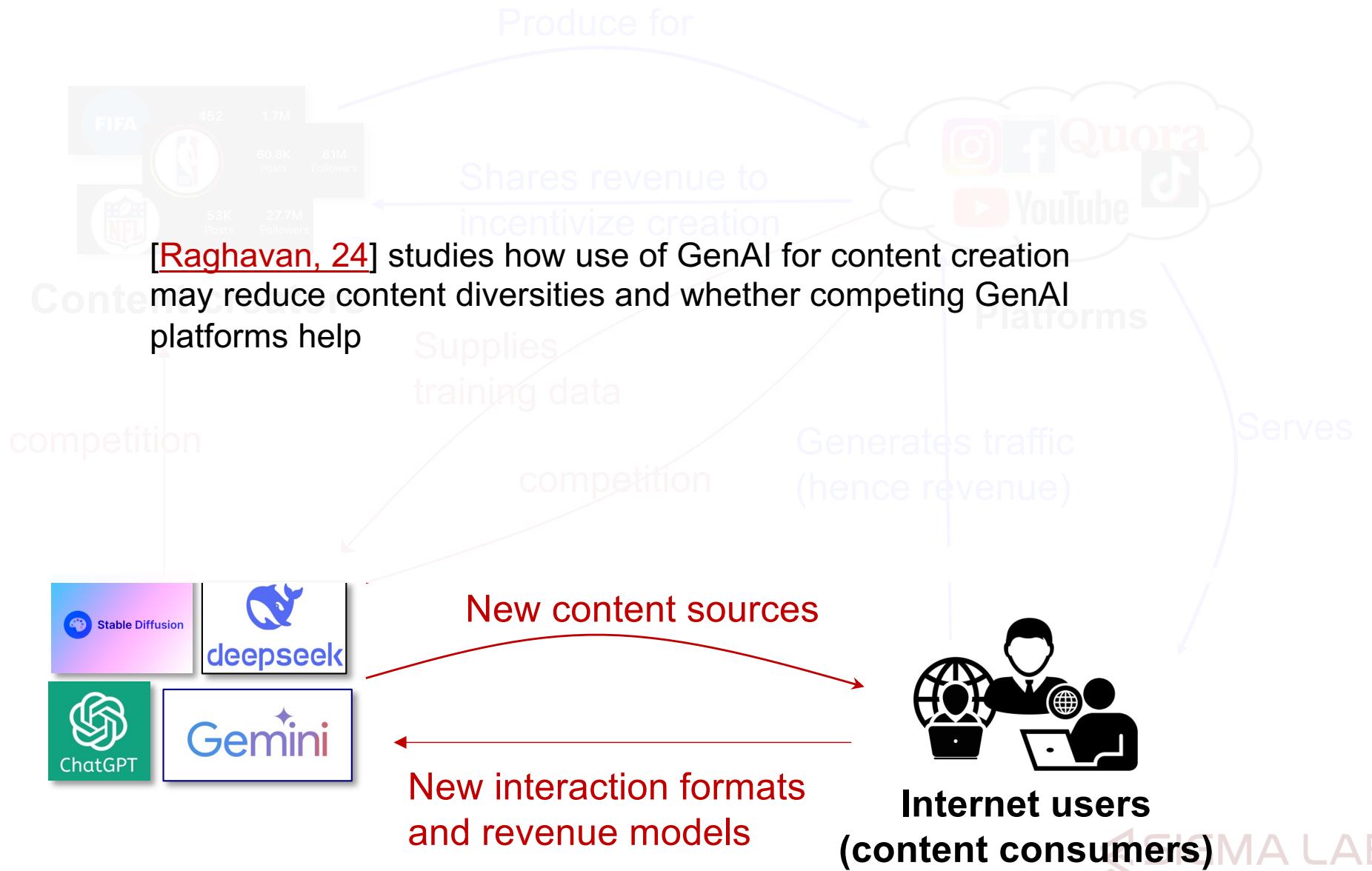
Interesting Recent Works; Huge Amount of Future Directions



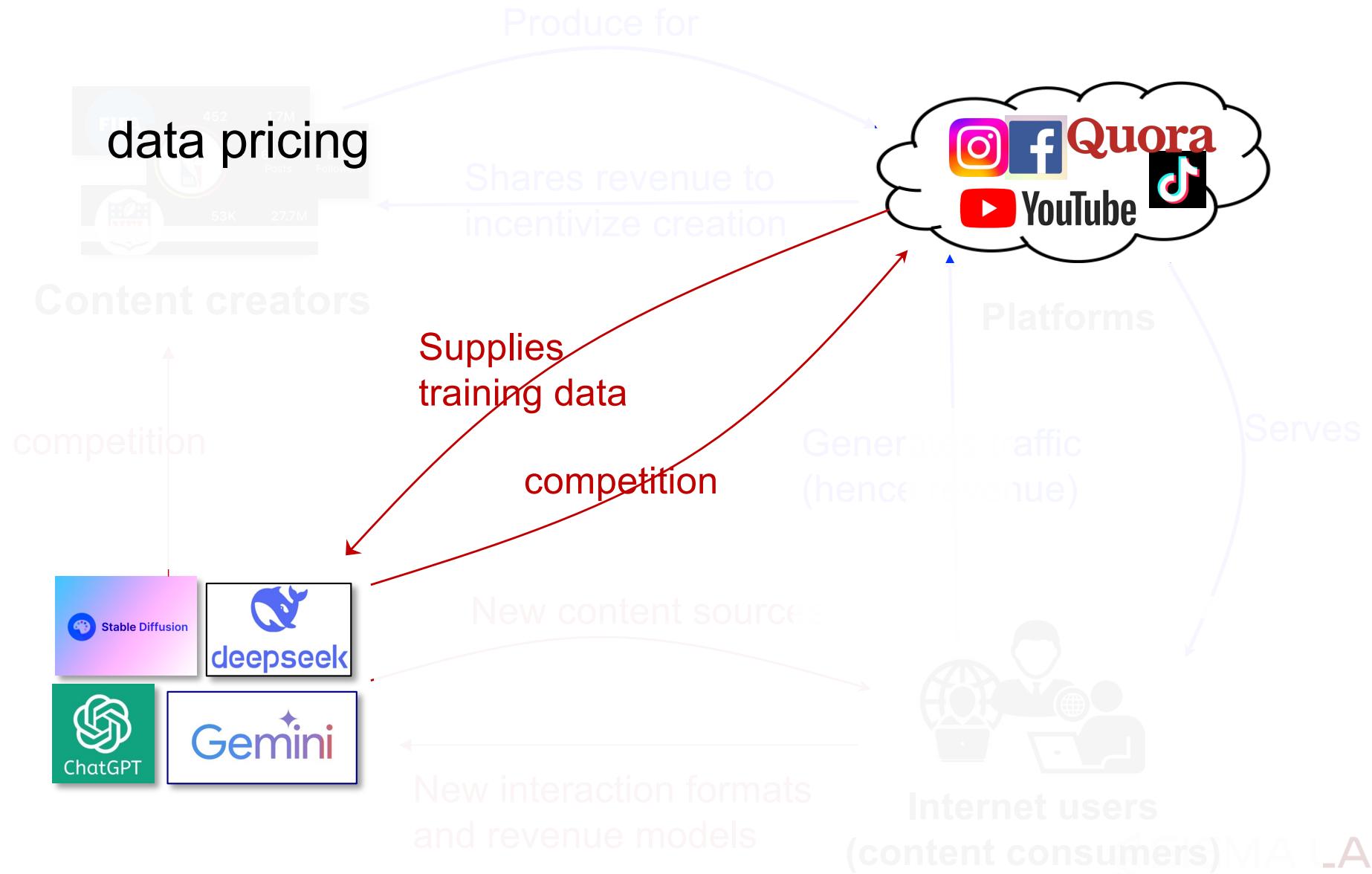
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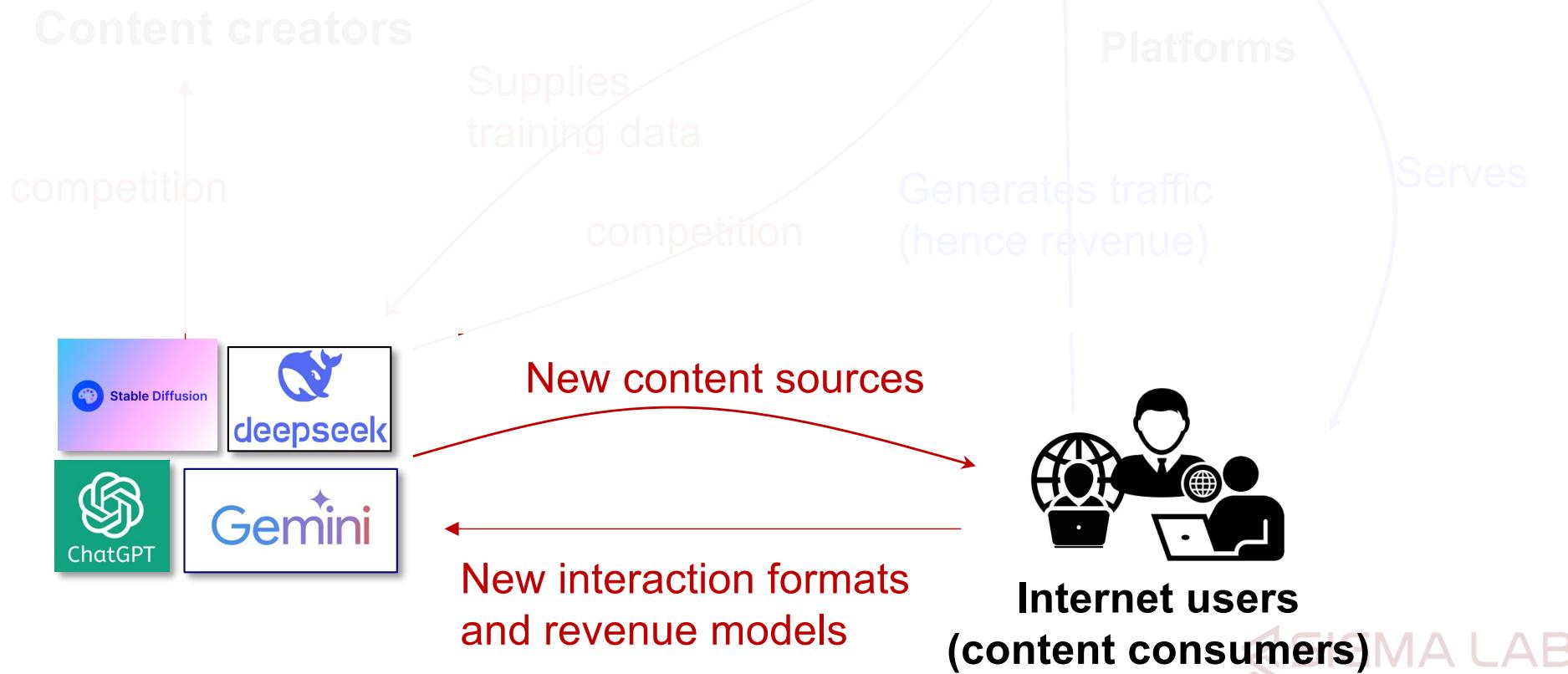
Natural and Important Mechanism Design Questions



Natural and Important Mechanism Design Questions

Preference aligned generation and new monetarization mechanisms

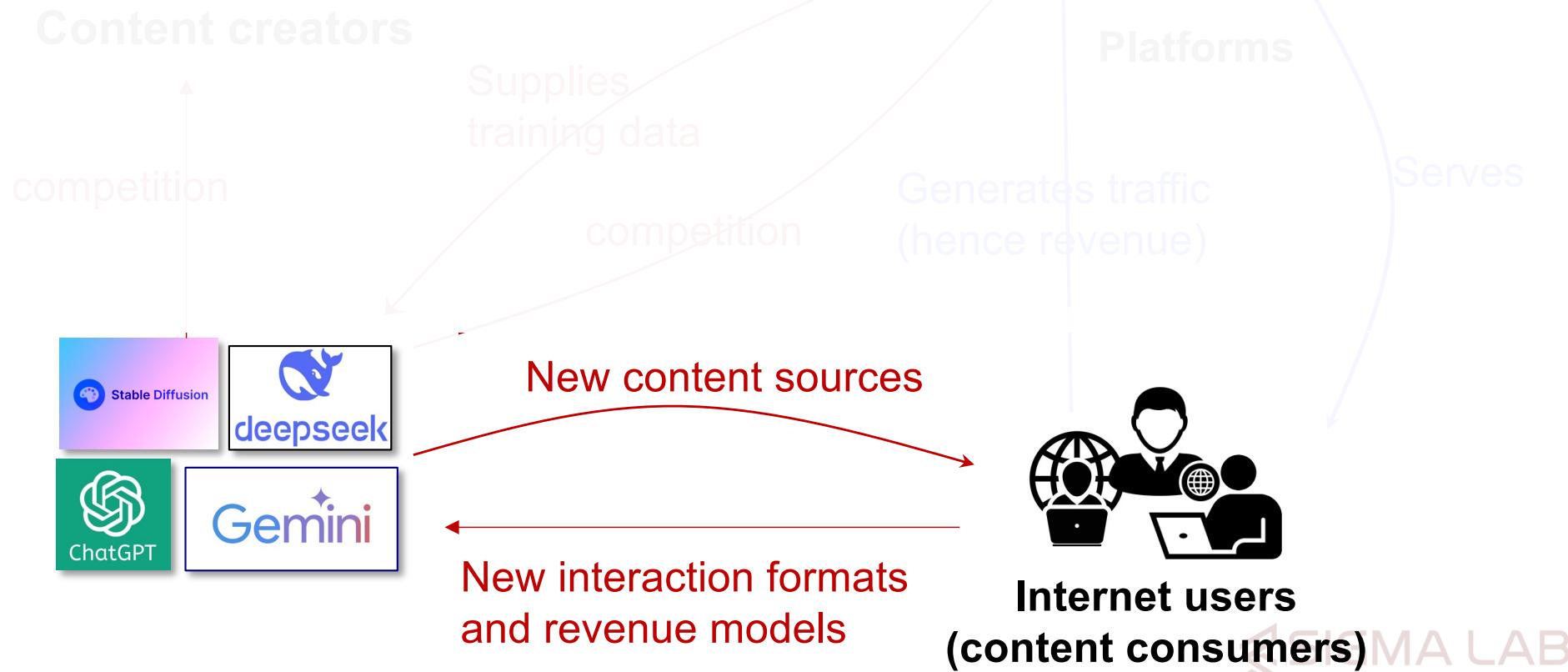
- [Duetting et al., WWW'24] studies how to generate texts that aligned with a group of users' preferences, with advertising as one motivation
 - Follow-up refinements and variants [Dubey et al. KDD'24, Soumalia et al'24] and position papers [Feizi et al 2023]



Natural and Important Mechanism Design Questions

Preference aligned generation and new monetarization mechanisms

- [Duetting et al., WWW'24] studies how to generate texts that aligned with a group of users' preferences, with advertising as one motivation
 - Follow-up refinements and variants [Dubey et al. KDD'24, Soumalia et al'24] and position papers [Feizi et al 2023]



Mechanism Design for LLMs

Motivations

In many applications, different parties prefer different generations

Research Question:

How to allow different parties to influence an LLM's generation by incentivizing them to express preferences “truthfully”?

Application I: Internet Advertising

trip to Hawaii

The screenshot shows a search results page for "trip to Hawaii". At the top, there's a search bar with the query, followed by a toolbar with icons for microphone, camera, and search. Below the search bar are filters: All, Images, Videos, Forums, News, More, Tools, Cost, All inclusive, Packages, Plane, Open now, Online appointments, Cheap, and Ess. Two ads are highlighted with a red box and arrow:

- Sponsored** [Stingray Resorts](#)
Experience the magic of Hawaii at Stingray Resort, where stunning views, luxurious accommodations, and endless activities await. Book your stay today and create unforgettable memories in the heart of paradise.

- Sponsored** [Maui Airlines](#)
Fly to Hawaii with Maui Airlines and experience the beauty of the Aloha State. We offer affordable flights to all the major islands, so you can start your Hawaiian vacation sooner. Book your flight today and let the island spirit take over.


Quora <https://www.quora.com/What-is-the-estimated-cost-for-a-vacation-in-Hawaii-for-two> ...

What is the estimated cost for a vacation in Hawaii for two ...

A excursion in Hawaii for two people will likely cost round \$3000-\$5000 for airfare, motel, food, and sports for 5-7 days.

1 answer · 15 votes: My wife and I spent two weeks on Maui last month (June, 2019), so I can p...

Go Hawaii <https://www.gohawaii.com/planning-your-trip/before-you-travel> ...

Before You Travel to Hawaii

The first step to an enjoyable trip to Hawai'i is being well-informed about what to bring and how to prepare before your visit.

Pet Restrictions · What To Pack · Airport Security

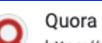

Currently, advertisers bid to have fixed ad creatives placed in certain slots in the page.

Application I: Internet Advertising

trip to Hawaii

The screenshot shows a search bar at the top with the query "trip to Hawaii". Below it is a navigation bar with "All", "Images", "Videos", "Forums", "News", "More", and "Tools" buttons. A row of filters follows: "Cost", "All inclusive", "Packages", "Plane", "Open now", "Online appointments", "Cheap", and "Ess". The main content area displays a sponsored ad with a blue border. The ad text reads: "Sponsored Fly to paradise with [Maui Airlines](#) and experience the magic of Hawaii at [Stingray Resort](#). Stunning views, luxurious accommodations, and endless activities await. Book your dream vacation today and create unforgettable memories." To the right of the text are two images: a stingray swimming in the ocean and a yellow and white airplane in flight. Below the ad is a Quora post snippet with a "Quora" logo, a link to the post, and a truncated title.

In the future, it could be a creative co-branding ads!



Quora

<https://www.quora.com> > What-is-the-estimated-cost-fo... :

What is the estimated cost for a vacation in Hawaii for two ...

A excursion in Hawaii for two people will likely cost round \$3000-\$5000 for airfare, motel, food, and sports for 5-7 days.

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Go Hawaii

<https://www.gohawaii.com> > planning-your-trip > before... :

Before You Travel to Hawaii

The first step to an enjoyable trip to Hawai'i is being well-informed about what to bring and how to prepare before your visit.

[Pet Restrictions](#) · [What To Pack](#) · [Airport Security](#)



Application I: Internet Advertising

trip to Hawaii

The screenshot shows a search interface with a search bar containing "trip to Hawaii". Below the search bar are navigation links for "All", "Images", "Videos", "Forums", "News", "More", and "Tools". There are also filters for "Cost", "All inclusive", "Packages", "Plane", "Open now", "Online appointments", "Cheap", and "Ess". A sponsored ad is displayed, featuring a travel poster for "PAIRADISE" with a plane flying over palm trees and a stingray in the water. The ad text reads: "Fly to paradise with [Maui Airlines](#) and experience the magic of Hawaii at [Stingray Resort](#). Stunning views, luxurious accommodations, and endless activities await. Book your dream vacation today and create unforgettable memories." Below the ad, there are two Quora posts: one about the estimated cost for a vacation in Hawaii for two, and another from Go Hawaii about what to pack before traveling to Hawaii.

Sponsored

Fly to paradise with [Maui Airlines](#) and experience the magic of Hawaii at [Stingray Resort](#). Stunning views, luxurious accommodations, and endless activities await. Book your dream vacation today and create unforgettable memories.

Quora
<https://www.quora.com/What-is-the-estimated-cost-for-a-vacation-in-Hawaii-for-two>

What is the estimated cost for a vacation in Hawaii for two ...
A excursion in Hawaii for two people will likely cost round \$3000-\$5000 for airfare, motel, food, and sports for 5-7 days.
1 answer · 15 votes: My wife and I spent two weeks on Maui last month (June, 2019), so I can p...

Go Hawaii
<https://www.gohawaii.com/planning-your-trip/before-you-travel-to-hawaii>

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Pet Restrictions · What To Pack · Airport Security

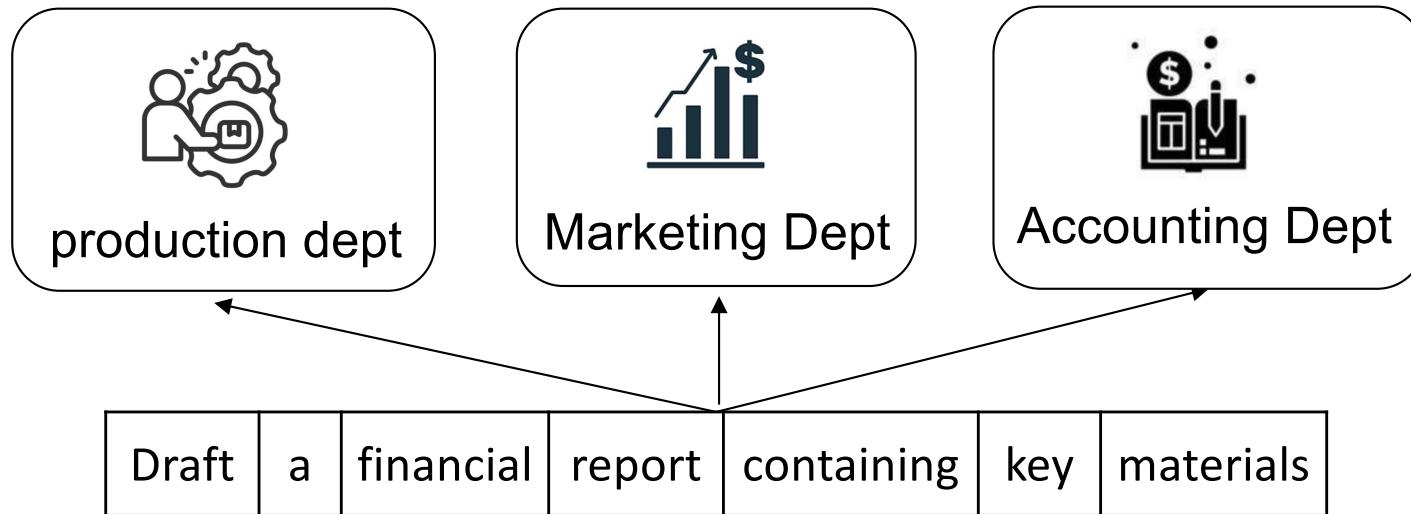
In the future, it could be a creative co-branding ads!

Even co-branding pictures!

The wish:

A way to auto-generate ad creative, which allows advertisers to express preferences and influence results via bids

Application 2: Enterprise LLMs



How to incentivize them to honestly express their preferences
to be aggregated into final output?

Desired Properties We Want

1. Avoid asking each agent (e.g., an advertiser) to report their value function or preferences over language outputs → unrealistic
 - ✓ Use LLMs to encode each agent's preferences
2. Each agent should still be able to influence the output
 - ✓ Allow each agent use a single bid to influence outcome (bid captures their intent strength)
3. Randomized token sampling → crucial for LLMs [Holtzman et al., 2019]
 - ✓ True by design
4. Efficiency → cannot call LLMs too many times
 - ✓ Each agent's LLM is called once
5. Technological compatibility → easy integration into current systems
 - ✓ Our design is a lightweight layer over existing LLMs

A proposal:

The Token Auction Model

The Token Auction

- Each advertiser's preference over outputs is encoded by an LLM
 - These LLMs are assumed **publicly known** (e.g., obtained via fine-tuning)

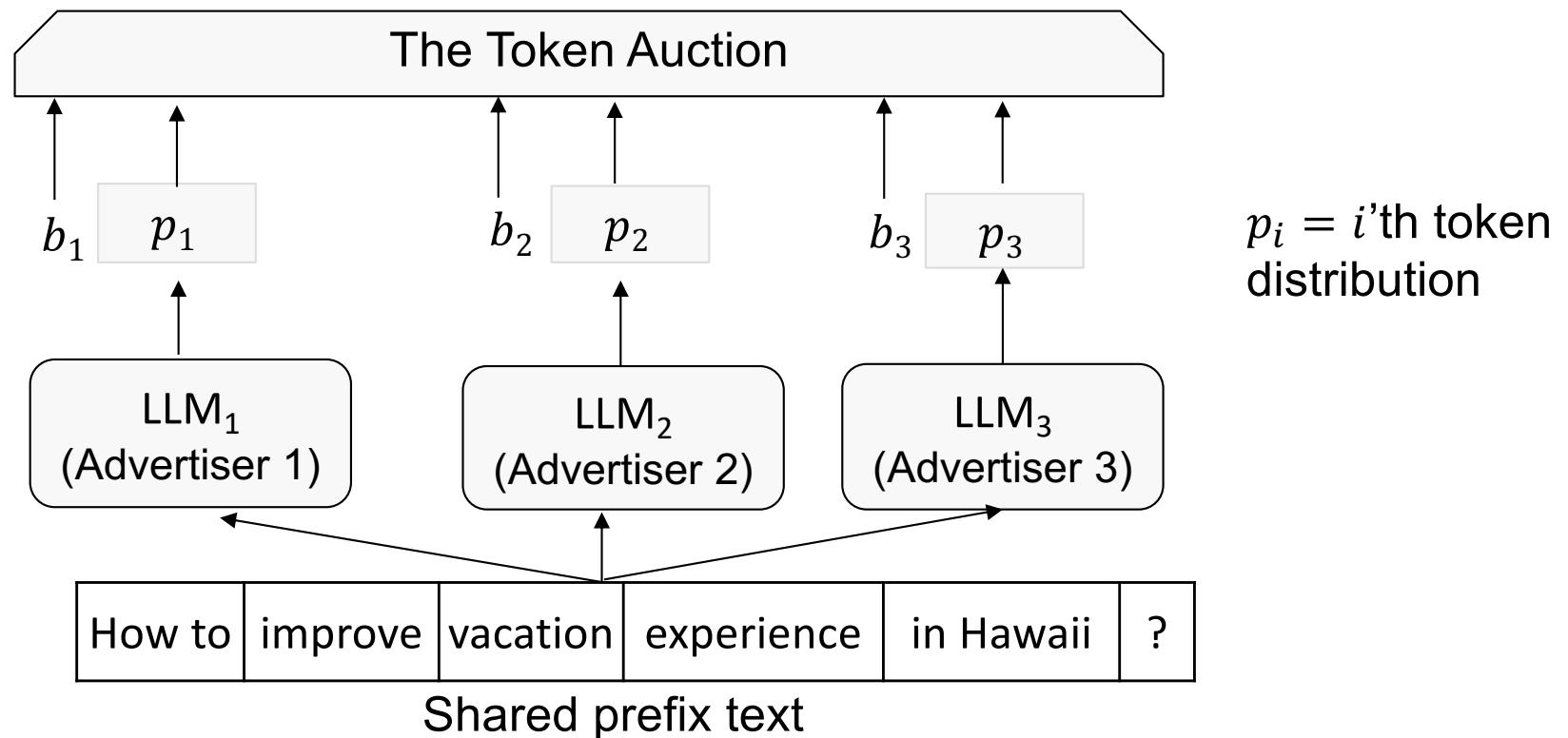
LLM₁
(Advertiser 1)

LLM₂
(Advertiser 2)

LLM₃
(Advertiser 3)

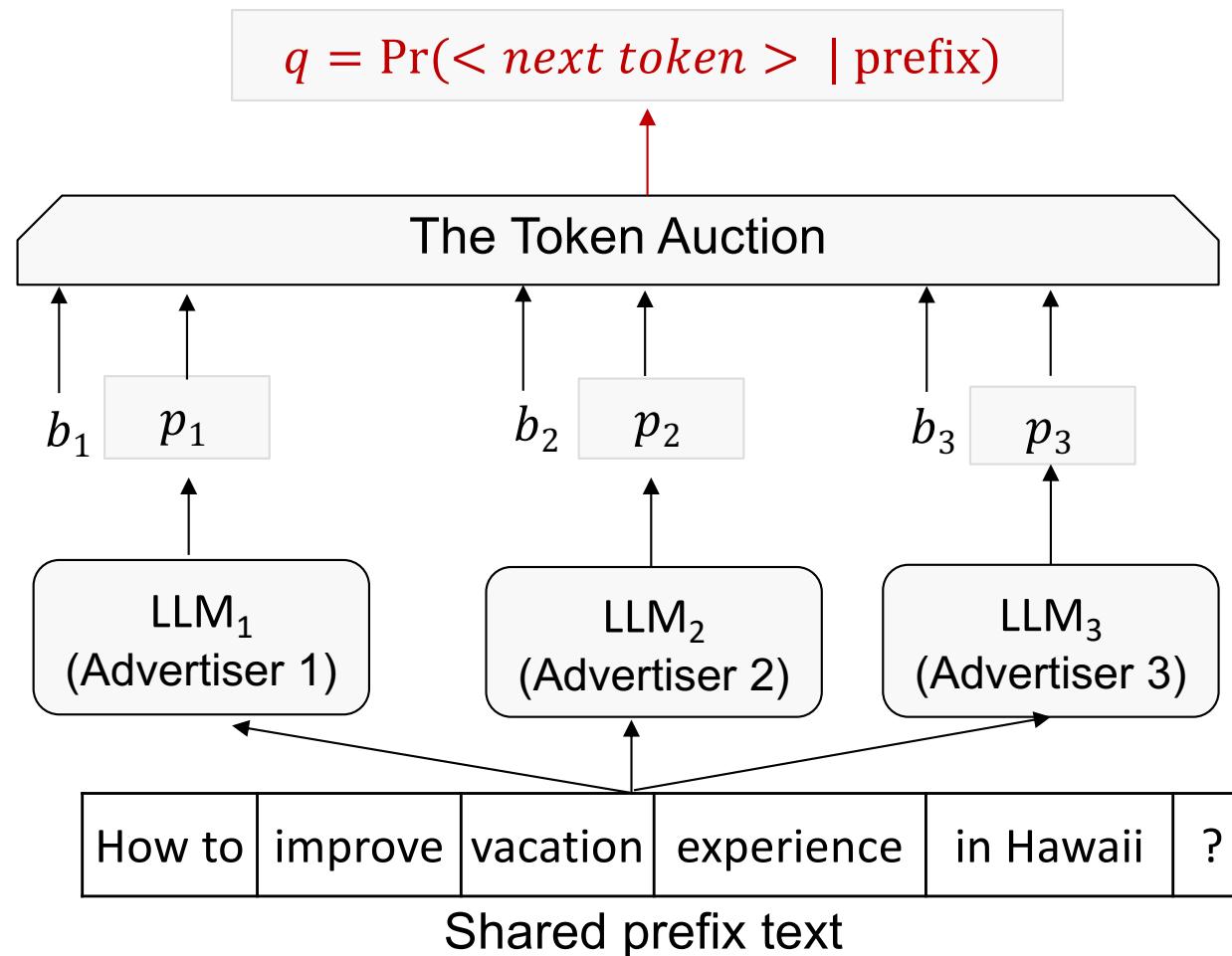
The Token Auction

- Auction runs when a prompt arrives
- Each advertiser can influence output via a bid
 - One of the LLMs can be the organic output with a default bid



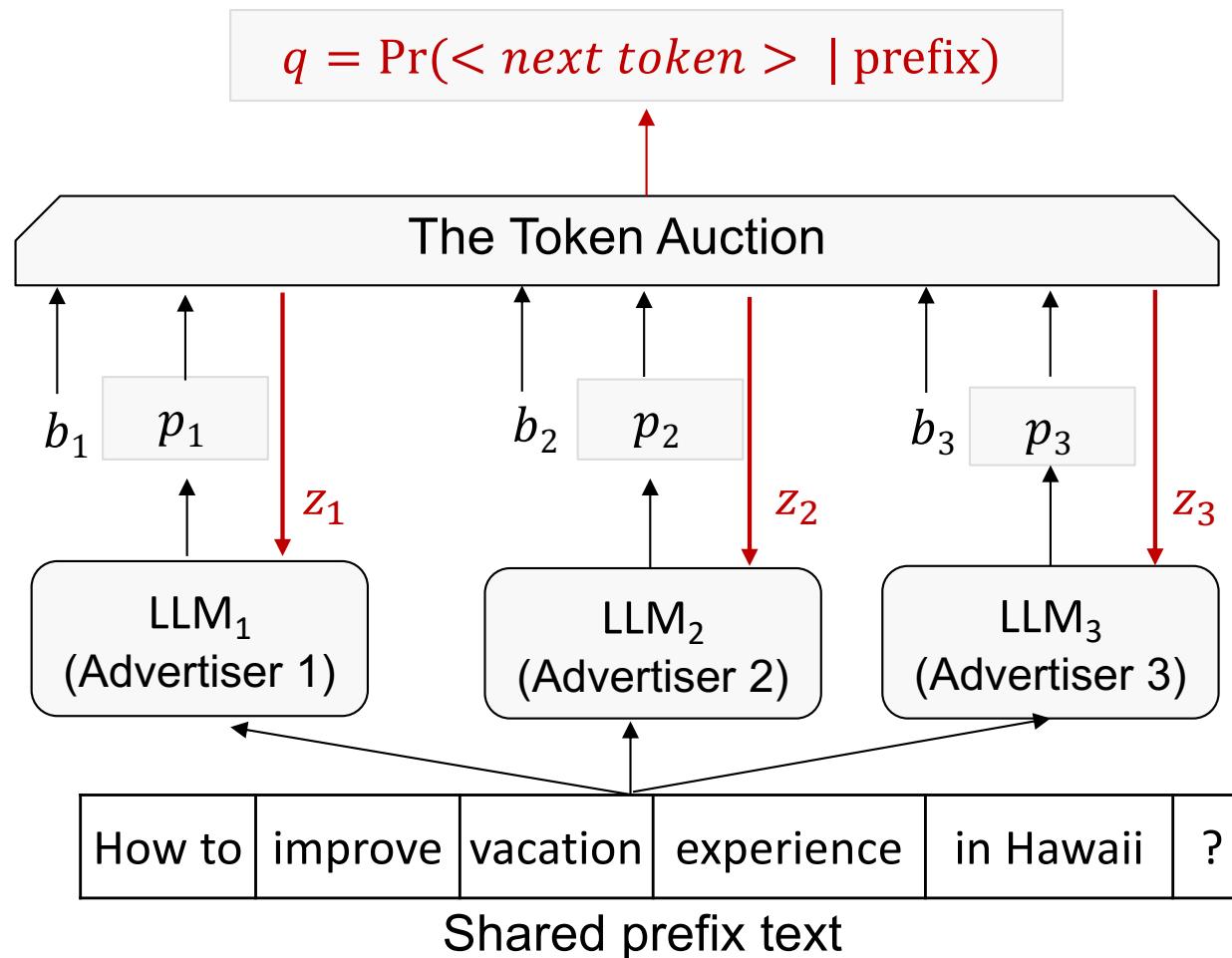
The Token Auction

- Auction determines aggregated distribution $q(\mathbf{b}; \mathbf{p})$



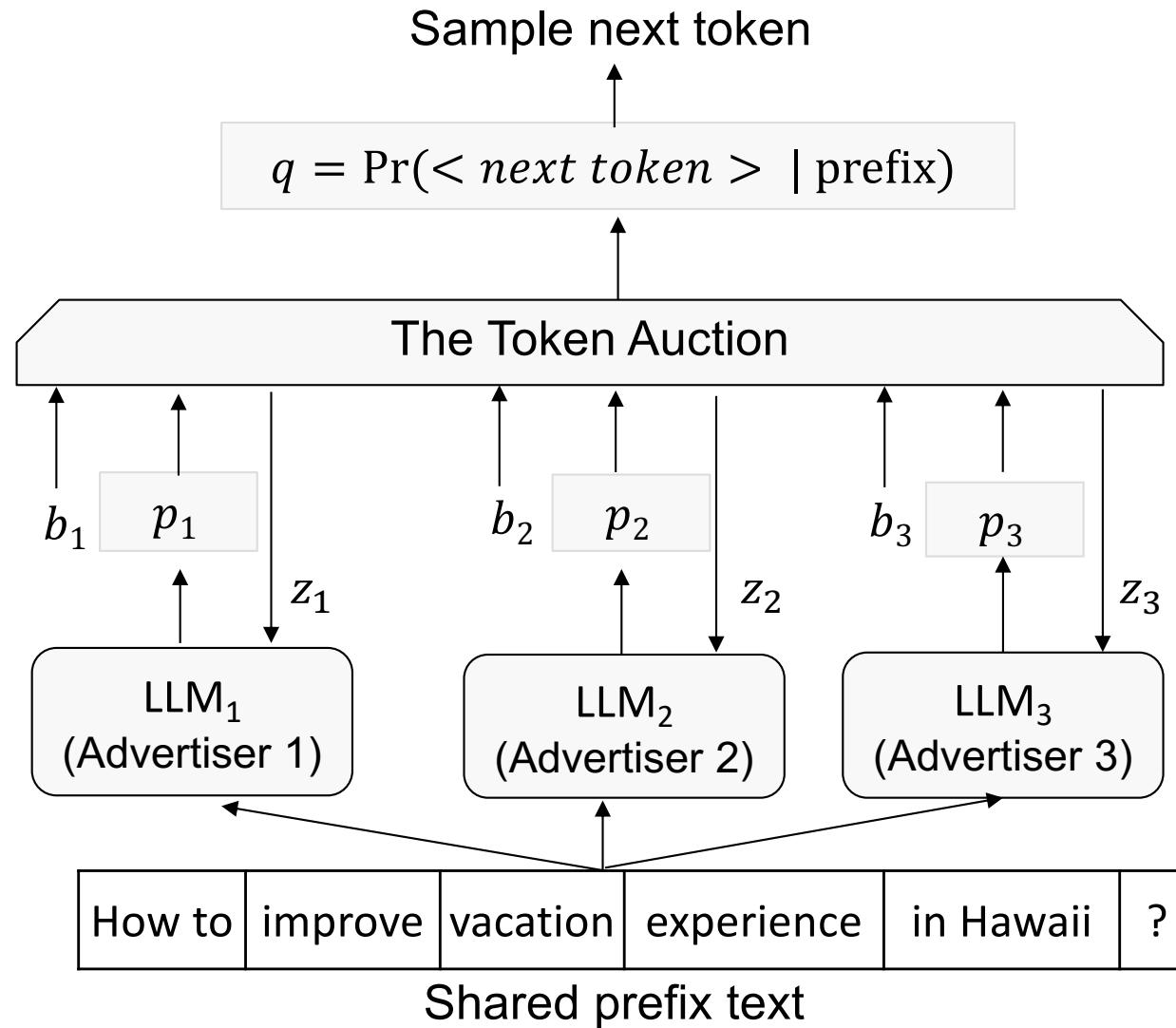
The Token Auction

- Auction determines aggregated distribution $q(\mathbf{b}; \mathbf{p})$ and payment $z_i(\mathbf{b}; \mathbf{p};)$



The Token Auction

Repeat this process with the same bids but updated prefix



Core Designs under the Auction Protocol

Aggregated function $q(\mathbf{b}; \mathbf{p})$ + payment $z_i(\mathbf{b}; \mathbf{p};)$ for each i

Why not VCG?

- The auction did not elicit value functions from bidders
- We employ *indirect* mechanism design, with *robust* consideration of agent preferences

Incentive Design in Our Indirect Mechanisms

Reduce incentive
design to
aggregation design

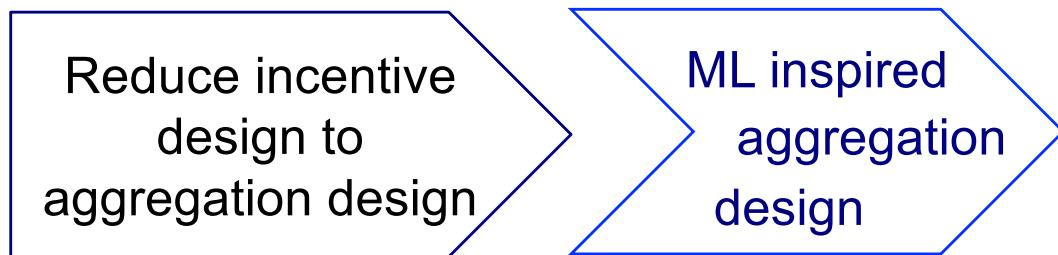
Desired incentive properties

1. Higher pay → robustly better distribution
2. Hold irrespective of others' bids

} Aggregation function
 $q(\mathbf{b}; \mathbf{p})$ must be
“monotone”

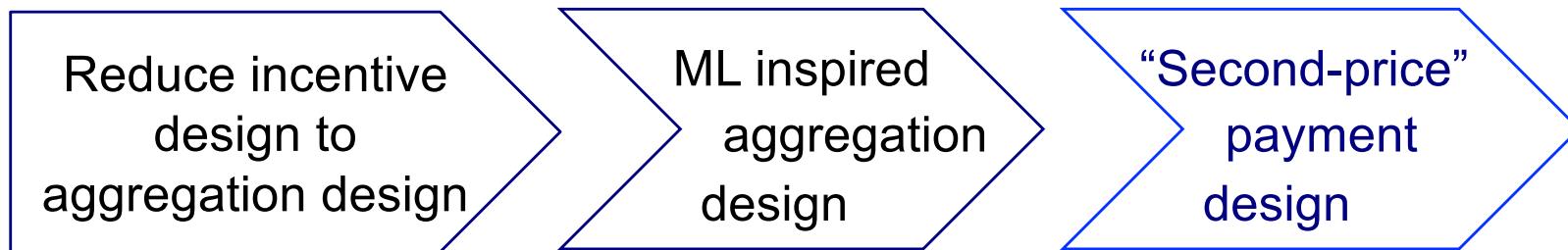
Proof employs Debreu's representation theorem

Incentive Design in Our Indirect Mechanisms



1. Training LLM based on combined data and KL-divergence loss → **Linear aggregation (monotone)**
2. RLHF based on combined agent preferences → **Log-linear aggregation (not monotone)**

Incentive Design in Our Indirect Mechanisms



A novel token sampling technique for monotone aggregation function that leads to natural “second-price” payment rule

Demonstration on Google's Bard LLM

- Two advertisers
- Create their LLMs via prompting

You are an expert of writing texts that naturally combines two ads together. Your choice of words and sentences is full of artistic flair.

Write a one-sentence ad for _____.

- Agent A use: **a flight to Hawaii using [Alpha Airlines].**
- Agent B use: **a vacation in Hawaii at the [Beta Resort].**

Bard-Generated Texts ($\lambda = \frac{b_1}{b_1+b_2}$)

λ	Linear aggregation function q_{KL}	Log-linear aggregation function \bar{q}_{KL}
1	Alpha Airlines: Your ticket to paradise.	
0.75	Alpha Airlines: Fly to Hawaii and experience the beauty of the islands with aloha. Beta Resorts: Stay at our resorts and enjoy the best of Hawaii.	Feel the magic of Hawaii with a flight on Alpha Airlines , now offering 20% off all flights when you book with us today!
0.6	Alpha Airlines flies you to Hawaii, where you can enjoy a week-long stay at the Beta resort for just \$1000.	Experience the magic of Hawaii with a flight on Alpha Airlines , now offering 20% off all flights when you book with us today!
0.55	Alpha Airlines flies you to Hawaii, where you can enjoy a week-long stay at the Beta resort .	Escape to the tropical paradise of Hawaii with [Alpha Airlines]!
0.5	Alpha Airlines flies you to Hawaii, where you can enjoy a beautiful sunset on the beach. Stay 3 nights and get the 4th free at the Beta Resort .	Experience the magic of Hawaii with a stay at the luxurious [Beta Resort] and a refreshing flight on [Alpha Airlines].
0.45	Fly Alpha Airlines to sunny Hawaii and enjoy the secluded beaches and private lagoons of the Royal Hawaiian Beta Resort .	Experience the magic of Hawaii with a stay at the luxurious [Beta Resort] and a special flight offer from [Alpha Airlines].
0.4	Fly Alpha Airlines to sunny Hawaii and enjoy the first-class treatment that awaits you at Beta Resort , all for one low price.	Experience the magic of Hawaii at the [Beta Resort], where you'll feel like you're in a tropical paradise.
0.25	Experience the magic of Hawaii at the Beta Resort , where the sun shines brighter and the waves crash louder — book your stay today with our exclusive 20% off discount!	Experience the magic of Hawaii at the Beta Resort , where you'll be pampered like royalty and surrounded by breathtaking beauty.
0	Hawaii's Beta Resort: a paradise where the sun shines brighter, the waves sing sweeter, and the sand feels softer.	

- Linear aggregation function (monotone) does appear to more smoothly transit from favoring agent A to favoring agent B
- Log-linear aggregation tends to say less and repeat more

Other Works in EconCS Space

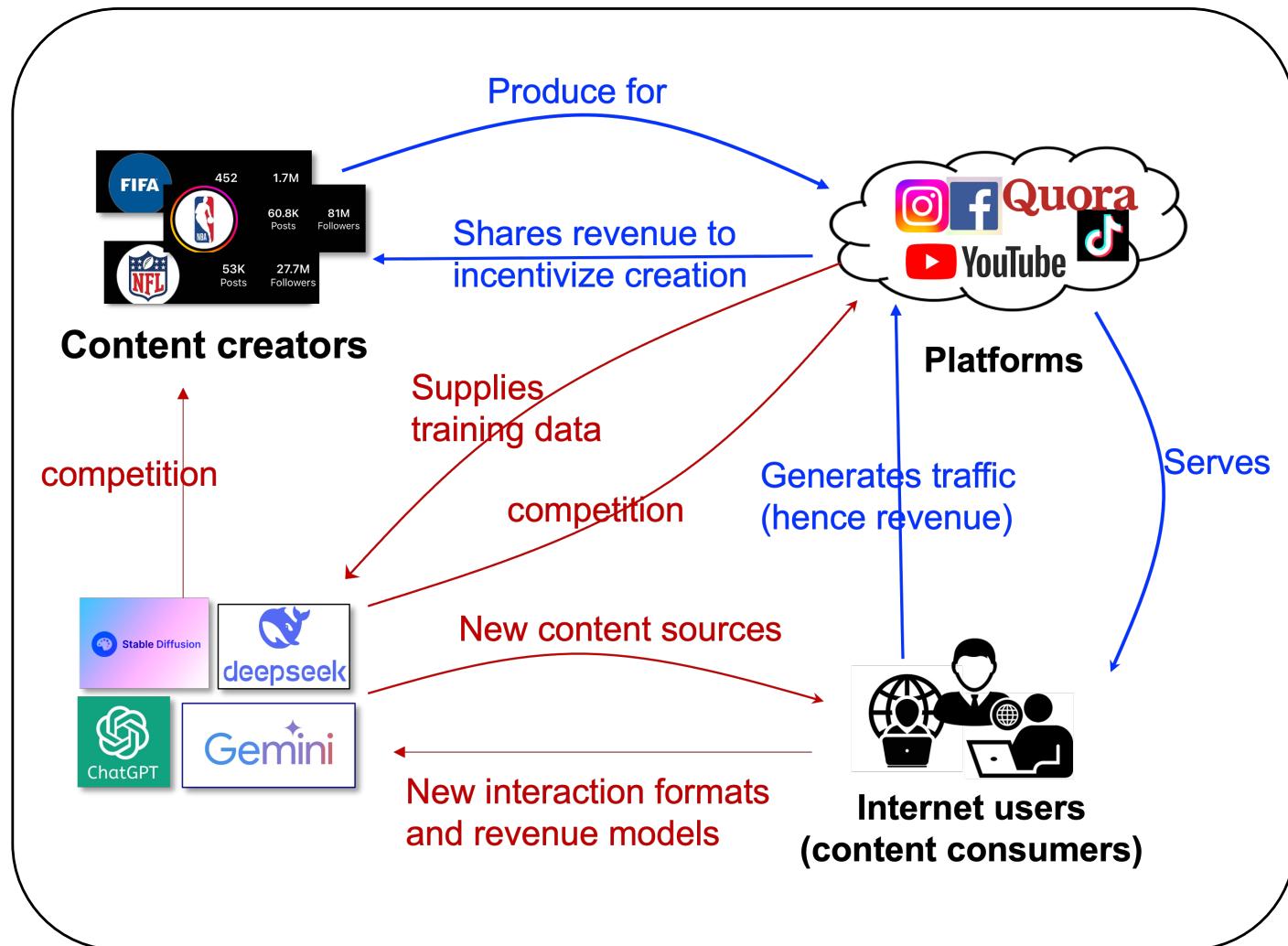
- This talk is biased towards algorithmic studies of non-cooperative competitions and mechanism design
 - Many recent works from economic/operational perspective
 - GenAI for social choice [[Fish et al., EC'24](#)] and preference alignment [[Conitzer et al. ICML'24](#)]
 - GenAI for peer prediction [[Lu et al., EC'24](#)]

Many Questions Remain to Be Understood/Solved

- Better and sustainable monetization of GenAI technology
- Fair and more equitable creator compensations
- Escape echo chamber
- Preserve/increase content diversity
- Sustainable human-GenAI co-evolution
- ...

Incentives and agency are crucial to both learning algorithms and market mechanisms for resolving these pressing issues

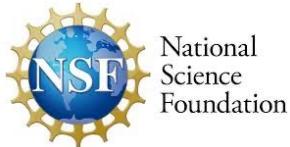
Summary



Thank You

Questions?

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National
Science
Foundation



SCHMIDT
SCIENCE



Office of Naval Research
ONR
Science & Technology

ARL
Army
Research
Lab

Google
Research

 **SIGMA LAB**
Strategic IntelliGence in Machine Agents