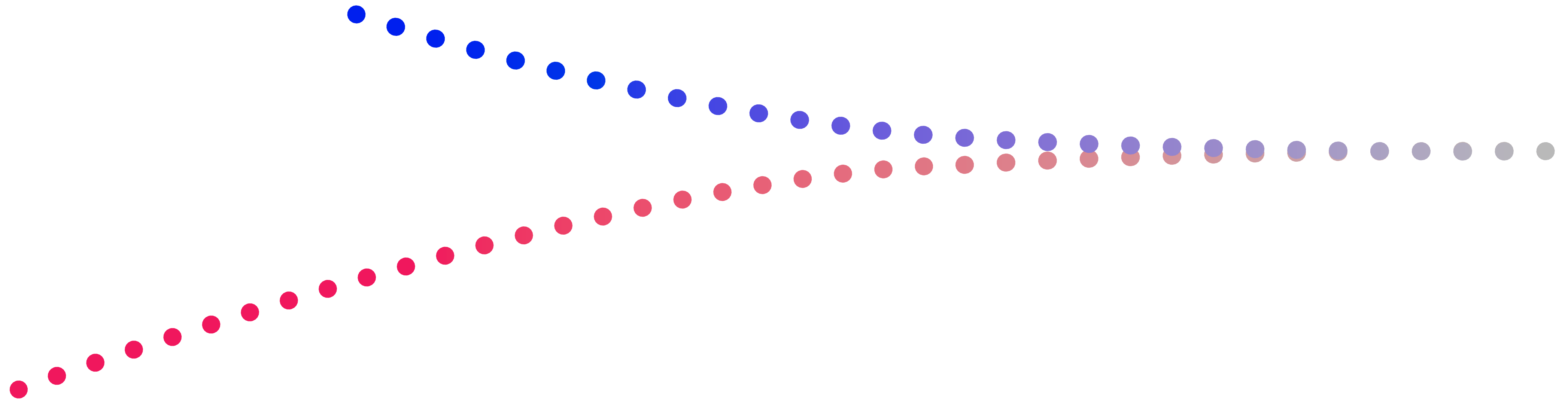


Empirical Mechanism Design— Designing Mechanisms from Data



Enrique Areyan Viqueira^{1,2}, Cyrus Cousins¹,
Yasser Mohammad², Amy Greenwald^{1,2}



BROWN

Motivation

Bangladesh

Bangladesh raises USD1.7bn from LTE frequency tender

15 Feb 2018

 Bangladesh

The Bangladeshi government has raised a total of BDT52.89 billion (USD1.68 billion) from its 4G spectrum auction, far below the expected BDT110 billion figure, with less than 30% of the 46.4MHz of spectrum put up for sale bought in the tender, The Daily Star writes. Shahjahan Mahmood, chairman of the BTRC, said the regulator was 'not happy' with the results of the auction, adding that the operators will have another opportunity to acquire spectrum at the same price within the next six months.

Market leader GrameenPhone will pay USD408 million for 5MHz in the 1800MHz band, in addition to a fee to convert its current holdings in the 900MHz and 1800MHz bands so as to make it technology neutral. Banglalink was awarded 2x5.6MHz in the 1800MHz band and 5MHz of paired spectrum in the 2100MHz band for a total fee of USD308.6 million (excluding VAT), while it will pay a further USD35 million to convert its existing spectrum

"Bangladesh raises USD1.7bn from LTE frequency tender." 15 Feb. 2018, [https://www.telegeography.com/products/commsupdate/articles/..](https://www.telegeography.com/products/commsupdate/articles/)

Motivation

Bangladesh

Bangladesh raises USD1.7bn from LTE frequency tender

15 Feb 2018

 Bangladesh

The Bangladeshi government has raised a total of USD1.7 billion from an LTE frequency auction, far below the expected BDT110 billion. The sale bought in the tender, The Daily Star writes, was 'not happy' with the results of the auction. The government will have to acquire the spectrum at the same price within the next six months.

Market leader GrameenPhone will pay USD400 million to convert its current holdings in the 900MHz and 1800MHz bands. It was awarded 2x5.6MHz in the 1800MHz band. The proceeds of USD308.6 million (excluding VAT), while it is the highest in the region.

"Bangladesh raises USD1.7bn from LTE frequency tender." 15 Feb. 2018, <https://www.telegeography.com/products/commupdate/articles/>..

India



Airwaves in the 2,300 megahertz band sold out as telecom operators spent to increase their 4G mobile broadband services. Photo: Mint

Spectrum auction ends, govt makes Rs65,789 crore, misses target

4 min read . Updated: 07 Oct 2016, 10:08 AM IST

Upasana Jain

Proceeds from spectrum auction a fraction of the Rs5.63 trillion of airwaves on offer; no bids were received for 700 MHz, 900 Mhz bands

"Spectrum auction ends, govt makes Rs65,789 crore, misses target." 07 Oct. 2016, <https://www.livemint.com/Industry/xt5r4Zs5RmzjdwuLUdwJMI/>..

Motivation

Bangladesh

India

Ghana

Bangladesh raises USD1.7bn from LTE frequency tender

15 Feb 2018

The Bangladeshi government has raised a total of BDT52.89 billion (USD1.68 billion) from its spectrum auction, far below the expected BDT110 billion figure, with less than 30% of the 46.4MHz of spectrum bought in the tender, The Daily Star writes. Shahjahan Mahmood, chairman of the BTRC, was 'not happy' with the results of the auction, adding that the operators will have another opportunity to buy spectrum at the same price within the next six months.

Market leader GrameenPhone will pay USD408 billion for 5MHz in the 1800MHz band, in order to convert its current holdings in the 900MHz and 1800MHz bands so as to make it technology neutral. It was awarded 2x5.6MHz in the 1800MHz band and 5MHz of paired spectrum in the 2100MHz band. It will pay a sum of USD308.6 million (excluding VAT), while it will pay a further USD35 million to convert its 6

"Bangladesh raises USD1.7bn from LTE frequency tender." 15 Feb. 2018, [https://www.telegeography.com/products/commupdate/articles/..](https://www.telegeography.com/products/commupdate/articles/)

"Spectrum auction ends, govt makes Rs65,789 crore, misses target."
07 Oct. 2016, [https://www.livemint.com/Industry/xt5r4Zs5RmzjdwuLUdwJMI/..](https://www.livemint.com/Industry/xt5r4Zs5RmzjdwuLUdwJMI/)

MTN Ghana poised to snap up unallocated 800MHz 4G spectrum

5 Apr 2019

 Ghana

Mobile network operator (MNO) MTN Ghana is lining up to purchase the two remaining 2x5MHz blocks of spectrum lots in the 800MHz band that were left unallocated after Vodafone Ghana acquired its own block of 2x5MHz for USD30 million last December, Adom News reports. 'MTN intends to acquire this remaining spectrum to enable it to continue to give its customers an increasingly better experience on the network,' MTN Corporate Services Executive Robert Kuzoe confirmed to Adom News in response to a questionnaire.

The MNO was precluded from the National Communications Authority (NCA's) auction of three separate 2x5MHz spectrum lots in the 800MHz band at the end of last year, on the grounds that it had already acquired a 2x10MHz lot in the same band back in December 2015. While the NCA confirmed at the end of the 2018 spectrum auction that 'two companies submitted applications, with Vodafone emerging as the only successful applicant,' the

"MTN Ghana poised to snap up unallocated 800MHz 4G spectrum."
05 April. 2019, [https://www.telegeography.com/products/commsupdate/..](https://www.telegeography.com/products/commsupdate/)

Setup

In traditional game theory, we have access to games' payoffs...

	C	D
C	3, 3	0, 5
D	5, 0	1, 1

Prisoner's dilemma

Setup

In traditional game theory, we have access to games' payoffs...

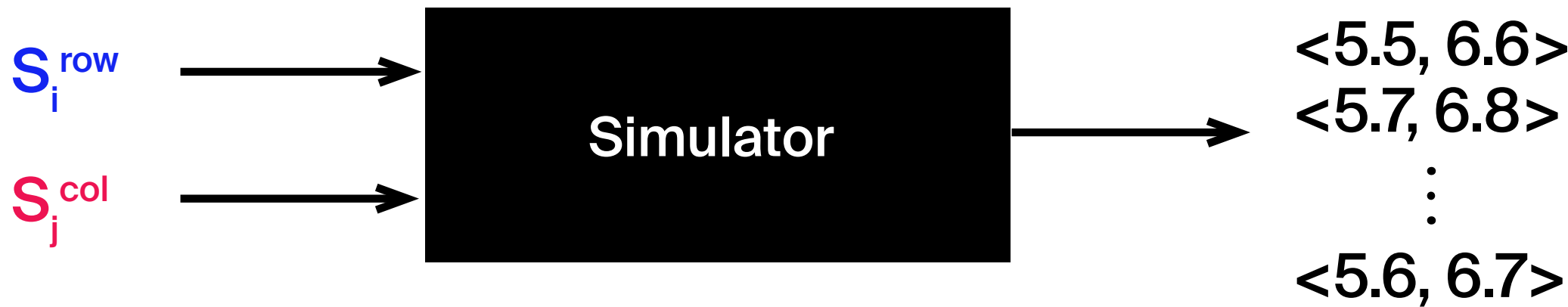
	C	D
C	3, 3	0, 5
D	5, 0	1, 1

Prisoner's dilemma

... but in the real-world, multi-agent systems are too complicated for traditional game-theoretical analysis

	S_1^{col}	S_2^{col}	$\dots$	S_n^{col}
S_1^{row}	?, ?	?, ?	$\dots$	?, ?
S_2^{row}	?, ?	?, ?	$\dots$	?, ?
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$
S_m^{row}	?, ?	?, ?	$\dots$	?, ?

Simulation-based game



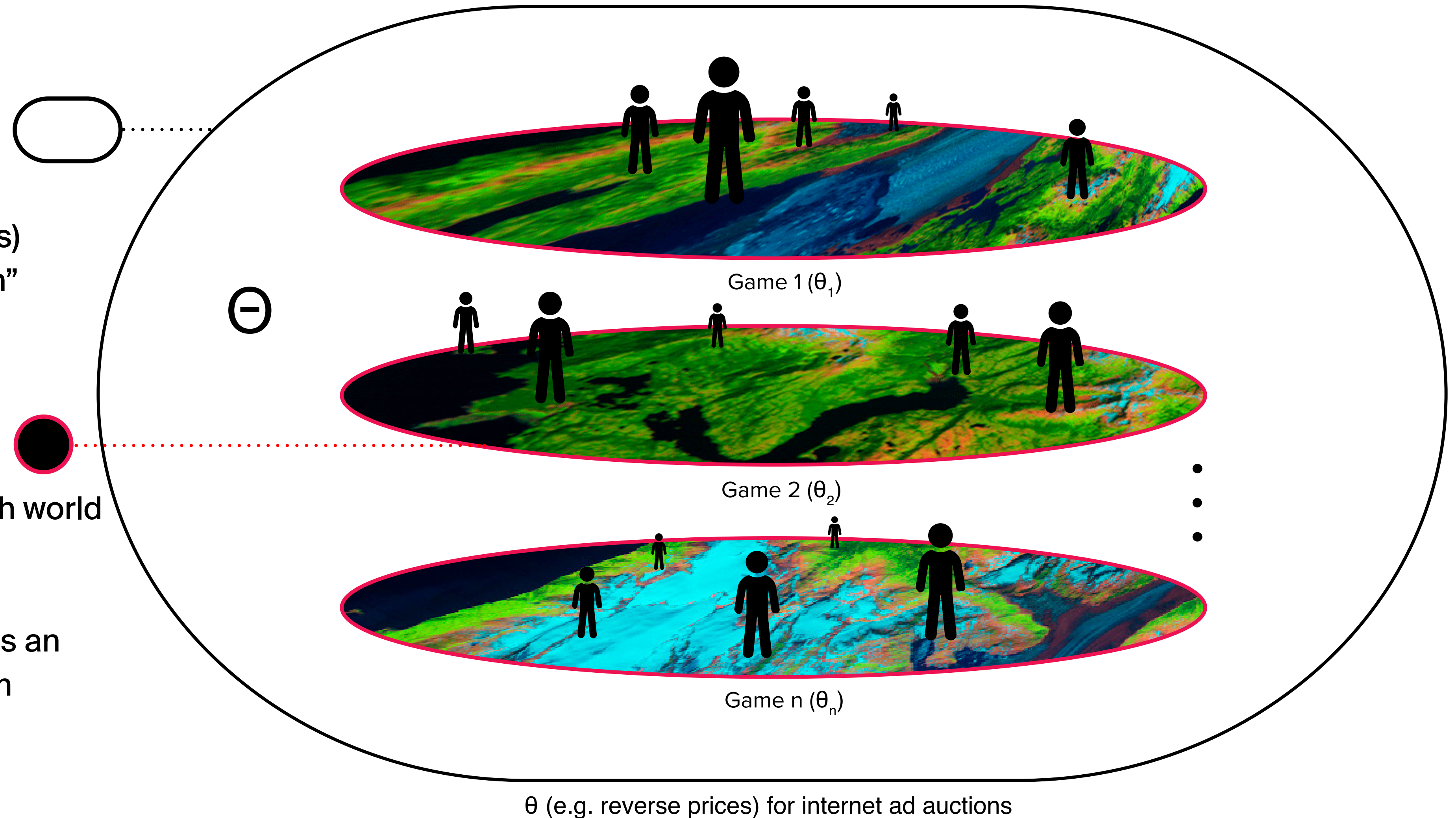
Parameterized mechanism design

Parameter search

- A set Θ describes all possible worlds (games)
- θ in Θ is a “mechanism”

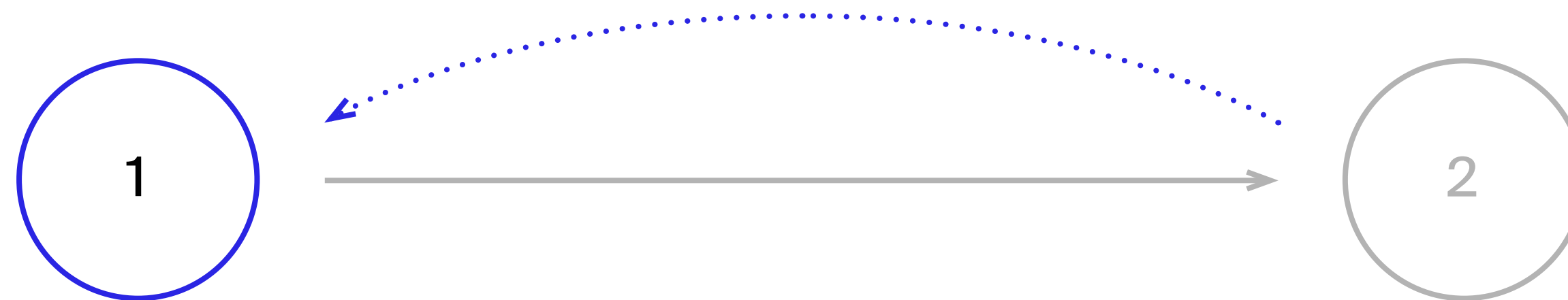
Equilibria estimation

- Multiple players in each world
- Find an equilibria with chosen θ
- The designer measures an objective at equilibrium



How should a **mechanism** designer (e.g., an auctioneer) set **parameters** (e.g. reserve prices), given access only to data (or to a simulator capable of **generating data**) about the **game** under **different** settings?

Our contributions

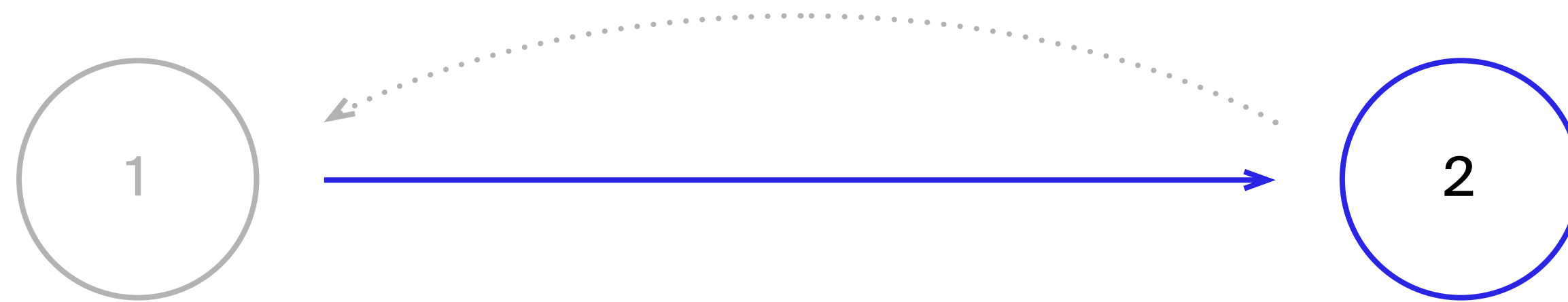


Derive a novel probably approximately correct (PAC) algorithm to learn the equilibria of games given access to noisy observations (or simulator) of the game's payoffs.

Formulate the problem of searching over Θ as a black-box optimization problem and use Bayesian techniques to incorporate piecewise constant noise that characterizes PAC learners.

↑ *Learning Simulation-Based Games from Data*,
Proceedings of the 18th International Conference on
Autonomous Agents and MultiAgent Systems
(AAMAS) 2019, Montreal, QC, Canada.

Our contributions



Derive a novel probably approximately correct (PAC) algorithm to learn the equilibria of games given access to noisy observations (or simulator) of the game's payoffs.

Formulate the problem of searching over Θ as a black-box optimization problem and use Bayesian techniques to incorporate piecewise constant noise that characterizes PAC learners.

↑ *Empirical Mechanism Design: Designing Mechanisms from Data*, Proceedings of the Thirty-Fifth Conference on Uncertainty in Artificial Intelligence (UAI) 2019, Tel Aviv, Israel.

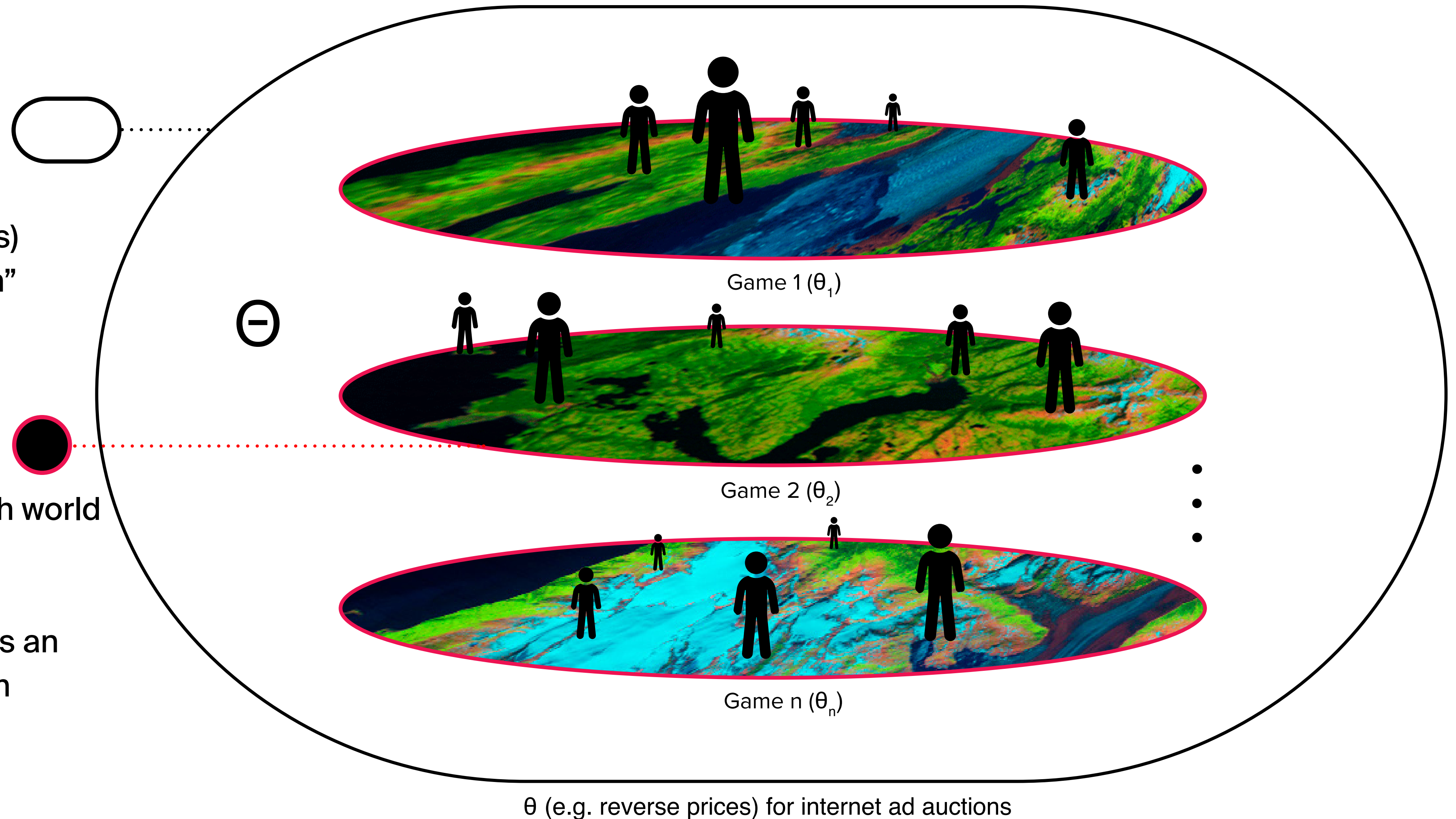
Parameterized mechanism design (déjà vu)

Parameter search

- A set Θ describes all possible worlds (games)
- θ in Θ is a “mechanism”

Equilibria estimation

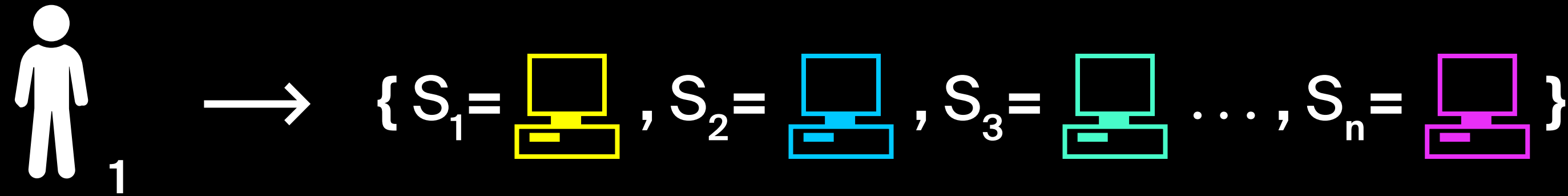
- Multiple players in each world
- Find an equilibria with chosen θ
- The designer measures an objective at equilibrium



Solving for equilibria (fixed parameters)

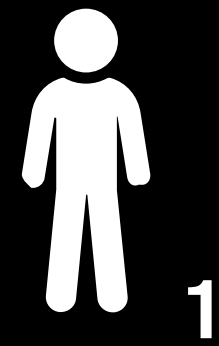
 Equilibria estimation

Players

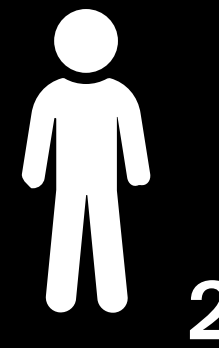


Solving for equilibria (fixed parameters)

Players



$$\{S_1 = \text{yellow monitor}, S_2 = \text{blue monitor}, S_3 = \text{green monitor} \dots, S_n = \text{purple monitor}\}$$



$$\{S_1 = \text{yellow monitor}, S_2 = \text{blue monitor}, S_3 = \text{green monitor} \dots, S_n = \text{purple monitor}\}$$

Solving for equilibria (fixed parameters)

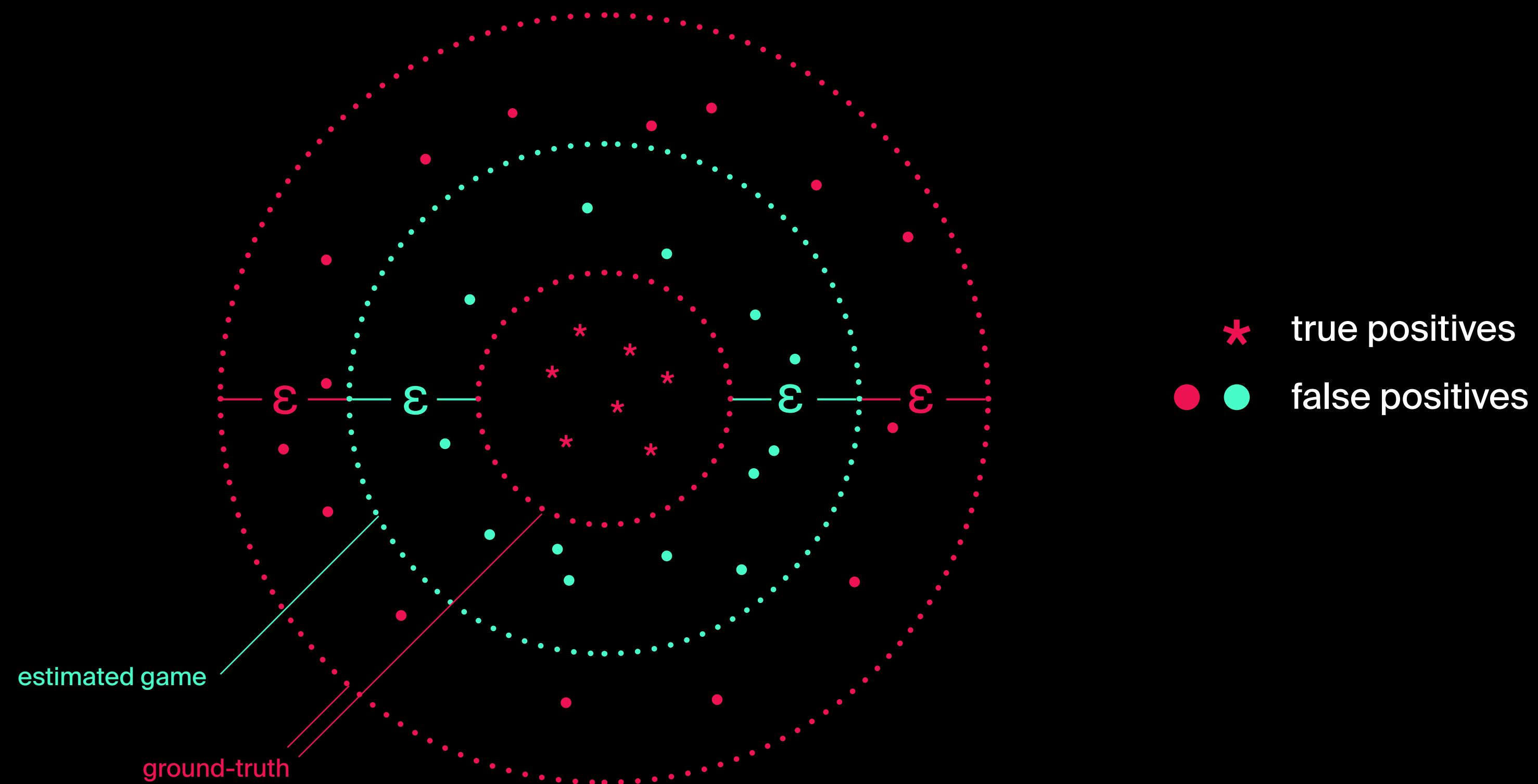
Players



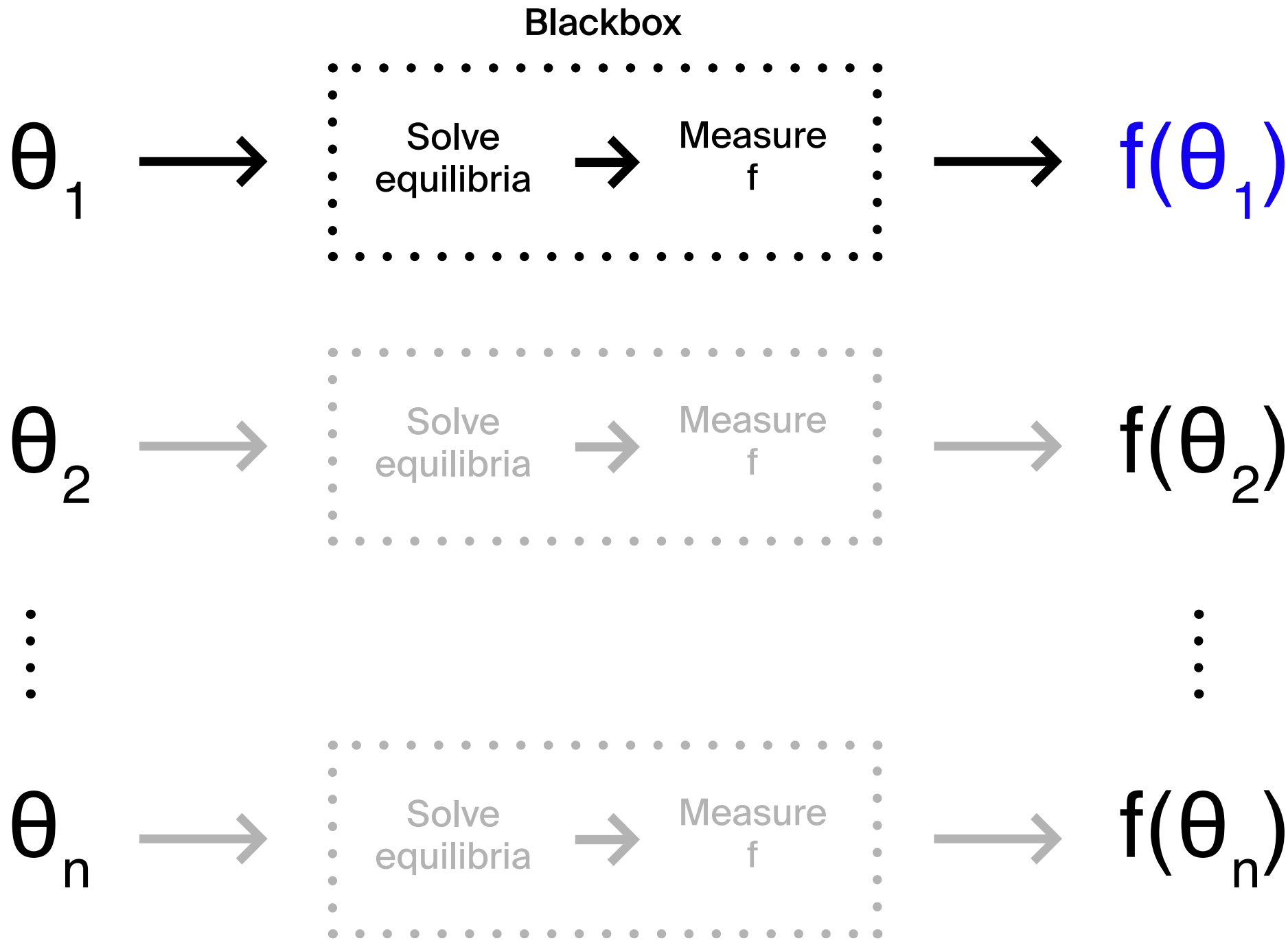
Approximating equilibria from data

With probability at least $1-\delta$

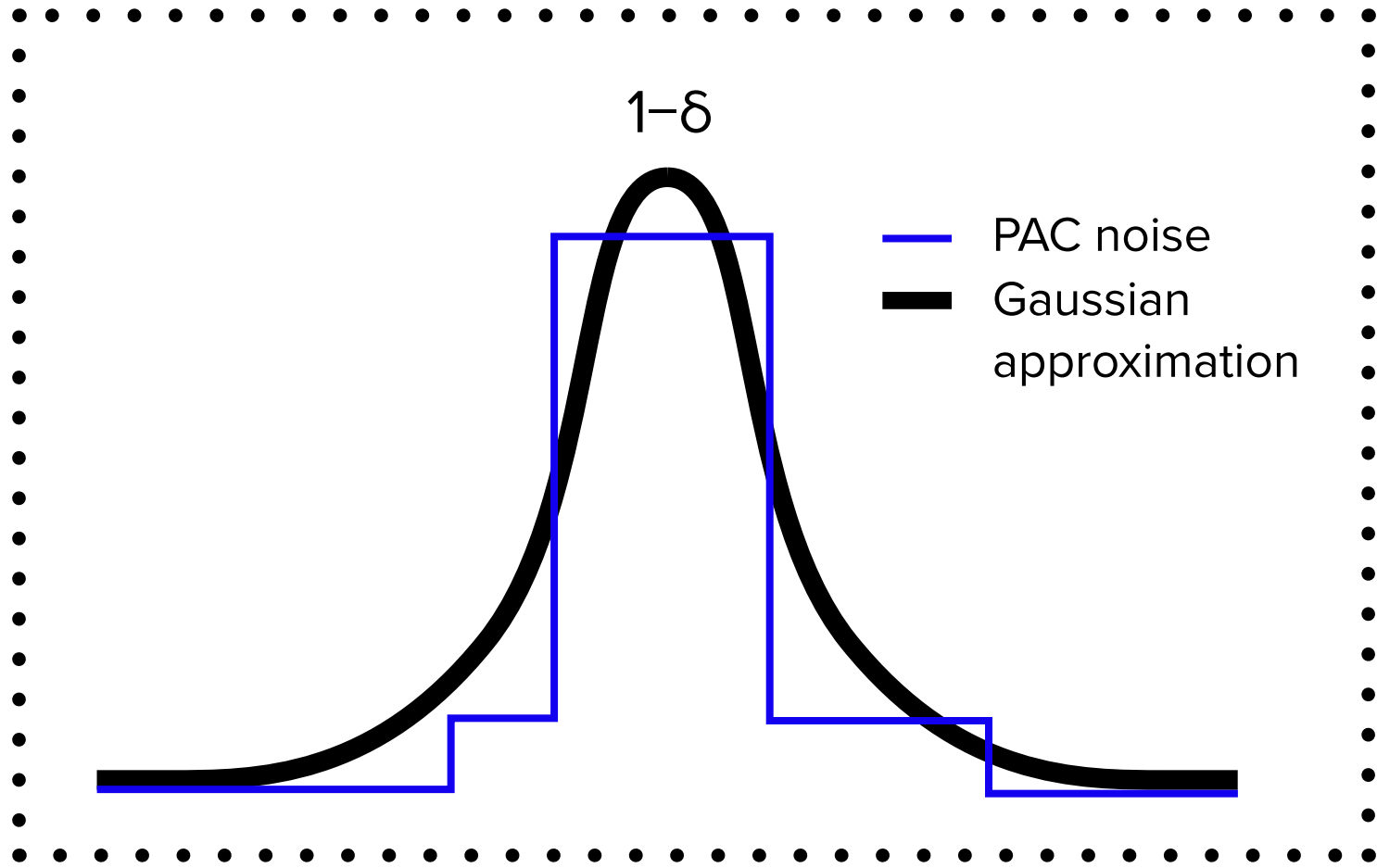
$$N(\text{ground-truth game}) \subseteq N_{2\varepsilon}(\text{estimated game}) \subseteq N_{4\varepsilon}(\text{ground-truth game})$$



Searching over the mechanism's parameters

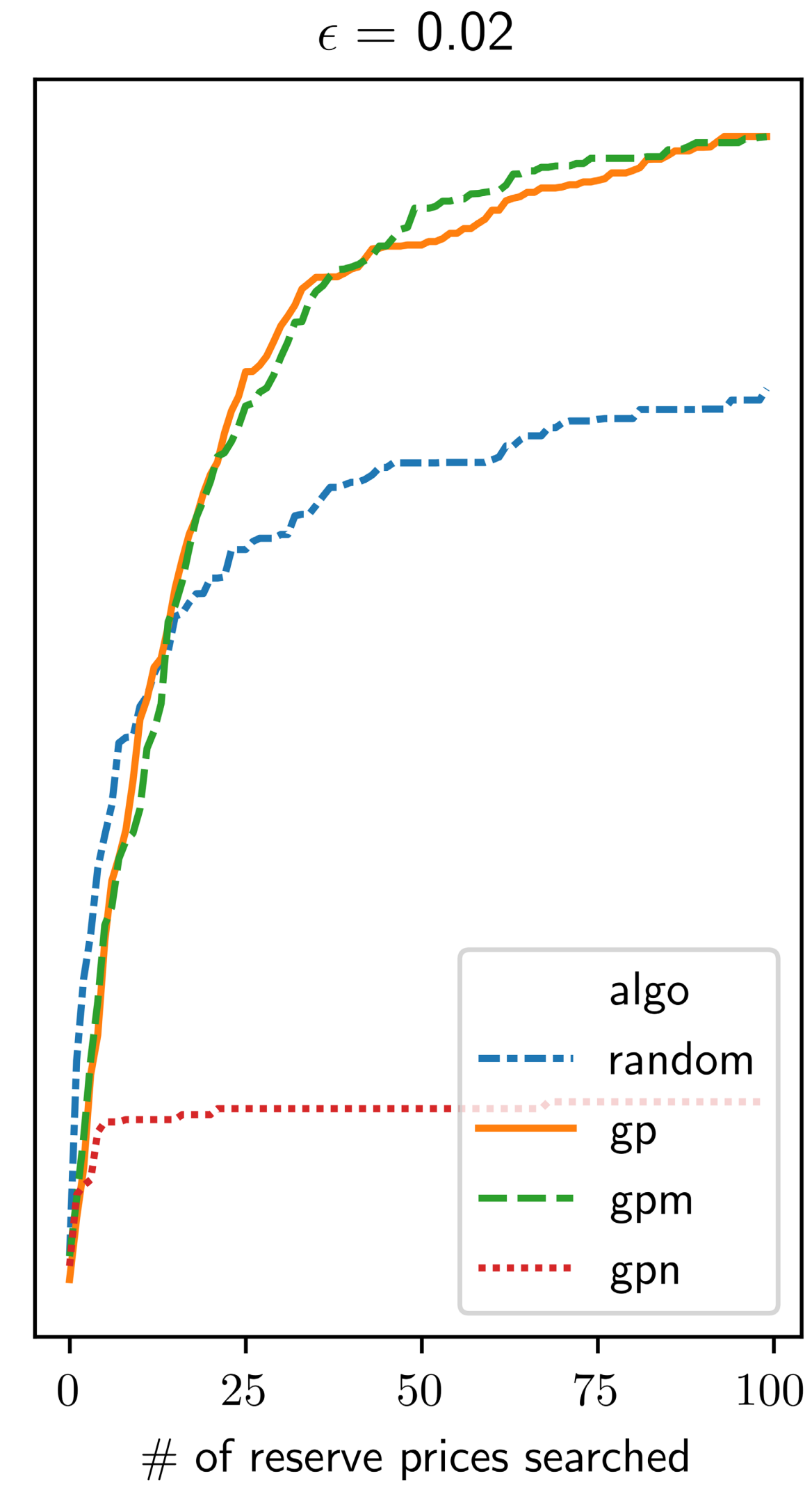
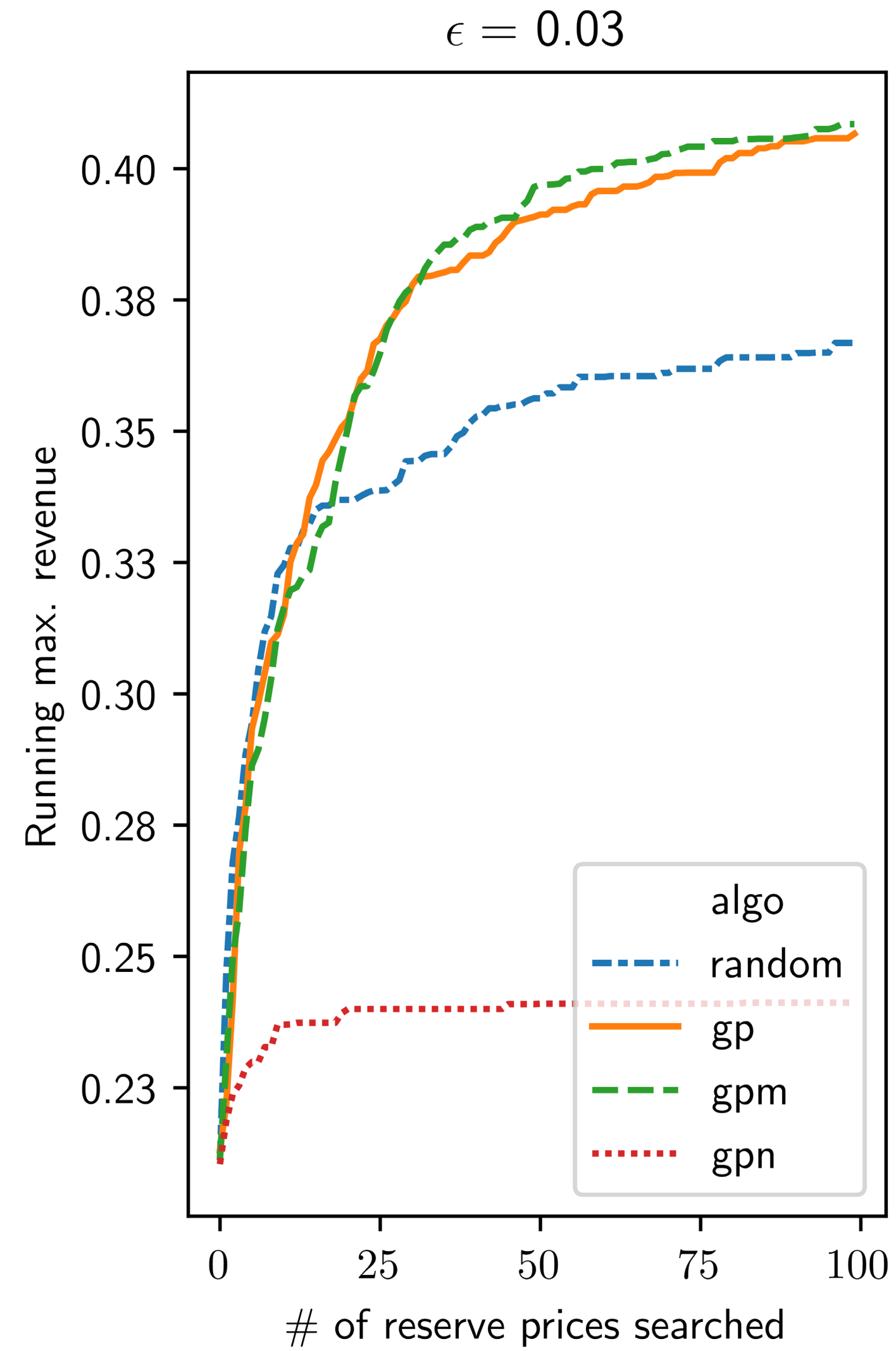


$f(\theta_1)$ = noisy measure of the designer's objective function



Fitting Gaussian to PAC noise

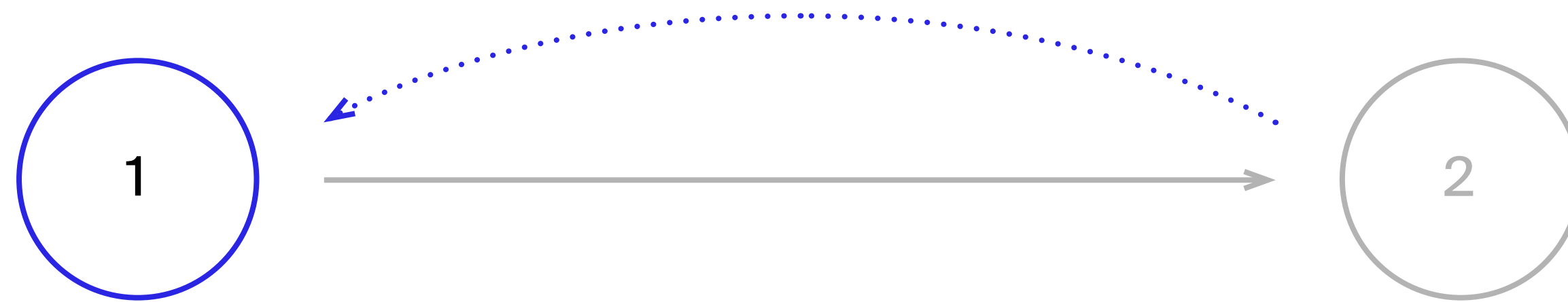
Results



Conclusion

I presented a two-part methodology to optimize systems inhabited by strategic agents.

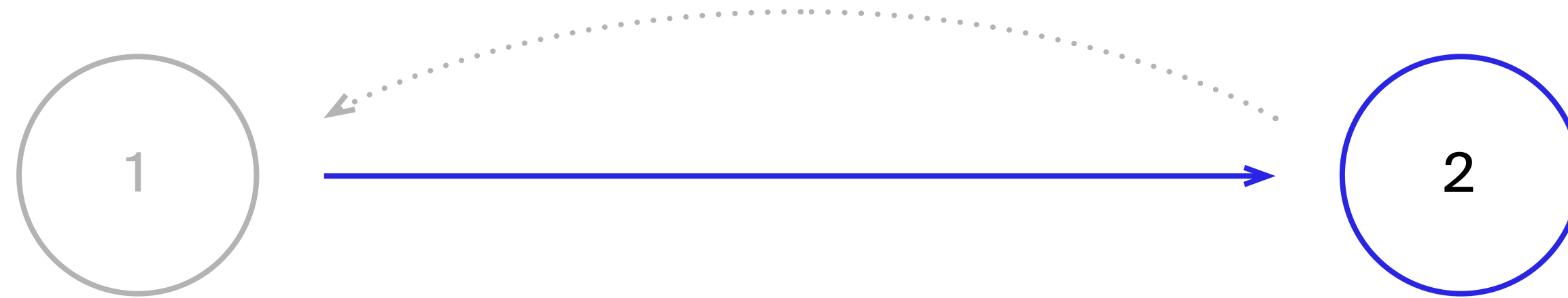
Conclusion



For a given game, solve for its equilibria by collecting data from simulations of gameplay.

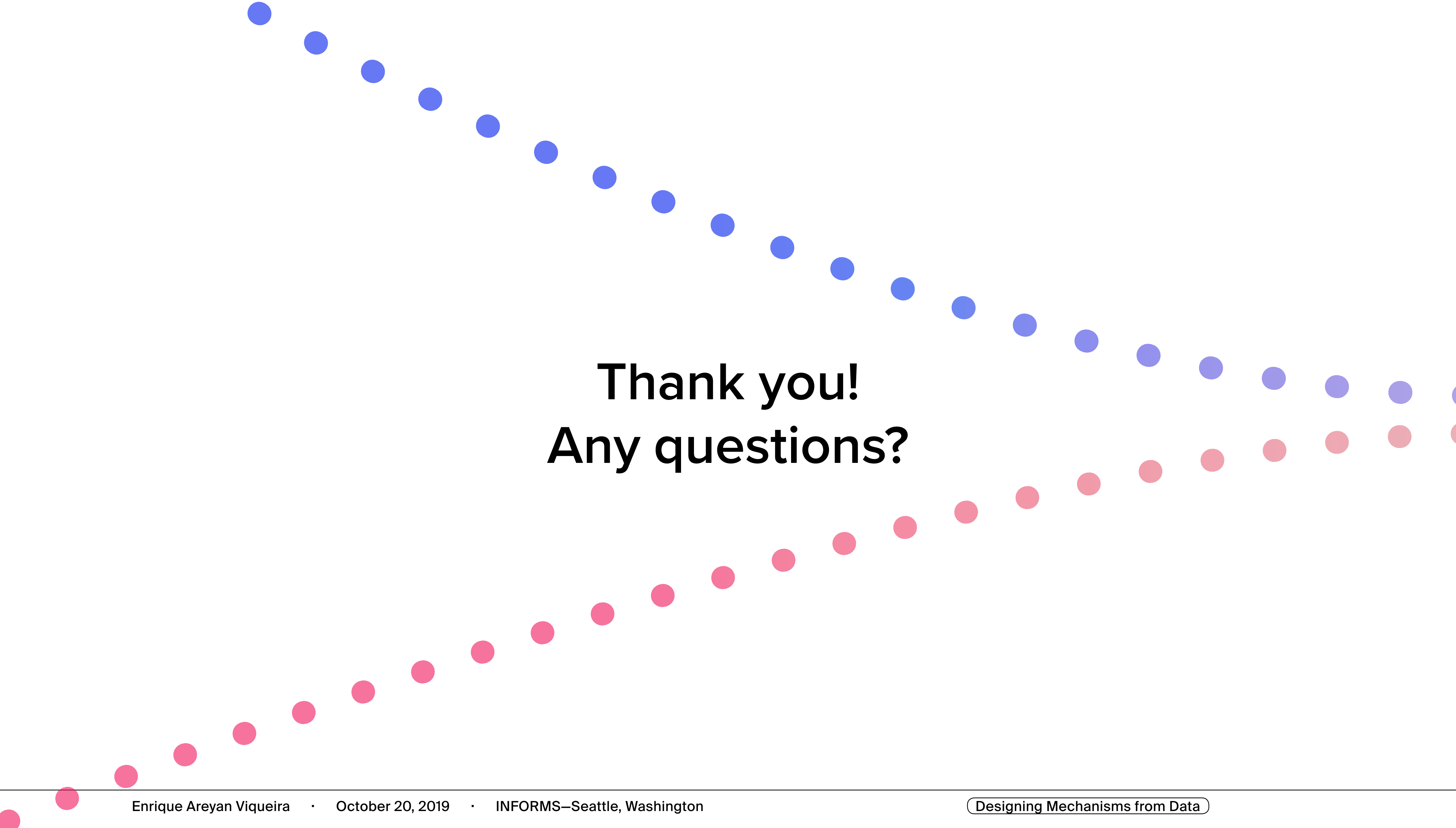
Search over the space of parameters for an approximately optimal one.

Conclusion



For a given game, solve for its equilibria by collecting data from simulations of gameplay.

Search over the space of parameters for an approximately optimal one.



Thank you!
Any questions?