Algorithmic Game Theory

Introduction

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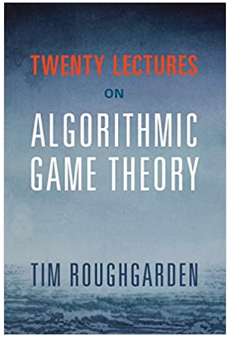
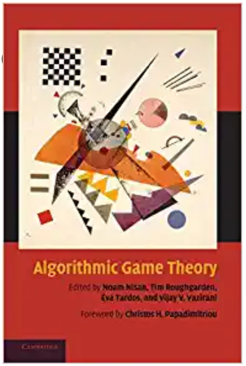
Textbooks and Materials



TWENTY LECTURES
ON
ALGORITHMIC
GAME THEORY

TIM ROUGHGARDEN

- Textbooks/Lectures:
  - *Twenty Lectures on Algorithmic Game Theory.* Tim Roughgarden. Cambridge University Press. 2016.
  - *Algorithmic Game Theory*. Noam Nisan, Tim Roughgarden, Eva Tardos, and Vijav V. Vazirani. Cambridge University Press. 2011.
- Other materials:
  - *Essentials of Game Theory: A Concise, Multidisciplinary Introduction* (Synthesis Lectur on Artificial Intelligence and Machine Learning). Leyton- Brown and Kevin, Shoham. Cambridge University Press. 2008.
- Course website:
  - https://josephcclin.github.io/courses/algorithmic_game_theory.htm



Algorithmic Game Theory

Edited by Noam Nisan, Tim Roughgarden, Éva Tardos, and Vijay V. Vazirani

Foreword by Christos H. Papadimitriou

Prerequisites

- Basic CS undergraduate courses in
    - Algorithms
    - Probability theory
    - Discrete mathematics
    - Coding

- Motivation.

- Curiosity.

Topics (adjusted accordingly)

- Introduction and Preliminaries
- Minimax Principles
- Social Choice
- Stable Matchings
- A Sketch of Nash's Theorem from Fixed Point Theorems
- Auctions & Mechanism Design Basics
- Equilibrium Concepts
- No-Regret Dynamics
- Network Creation Games
- Other Selected Topics

Grading Policy

- Attendance (10%)
- Assignments (30%)
- Midterm Presentation (30%)
  - Book chapters
  - **https://www.cs.cmu.edu/~sandholm/cs15-892F13/algorithmic-game-theory.pdf**
  - Chapters assigned through the **online random permutation generator**
- Final Presentation (30%)
  - Research papers

Grading policy for the presentations

- Order:
  - Midterm: According to the book chapters.
  - Final: According to the seat number ordering.
- Complete the presentation: 60 point
  - Duration for each presentation: 30~50 minutes.
- Raising questions: +2 point for each one (maximum +20 point)
- Clearly answering the teacher’s ≥ 4 questions: +5 point for each one.

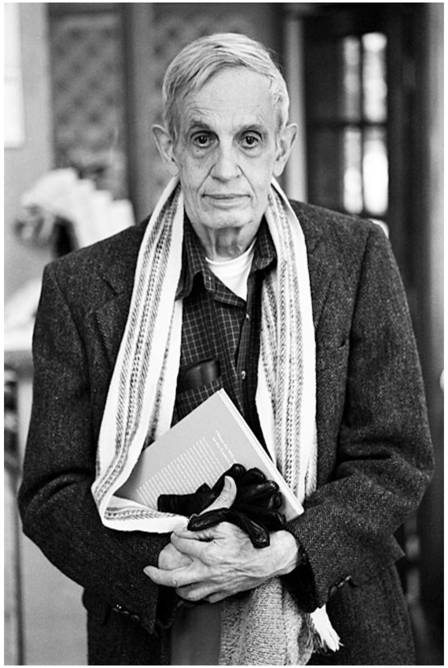
Where to find the paper? (suggestions)

*Please look for papers in 2020—present.

- **International conferences:**
    - **EC**: Proceedings of the ACM conference on Electronic commerce.
    - **NeurIPS**: Conference on Neural Information Processing Systems.
    - **AAAI**: Association for the Advancement of Artificial Intelligence.
    - **IJCAI**: International Joint Conferences on Artificial Intelligence.
    - **AAMAS**: International Conference on Autonomous Agents and Multiagent Systems.
    - **SAGT**: Symposium on Algorithmic Game Theory.
    - **WINE**: International Conference on Web and Internet Economics.
    - ...
- **Journals:**
    - **Games and Economic Behavior**
    - **International Journal of Game Theory**
    - **Social Choice and Welfare**

John Forbes Nash Jr. (1928–2015)

- American mathematician.
- Fundamental contributions to game theory.
- **Nobel Memorial Prize** in Economic Sciences with game theorists Reinhard Selten and John Harsanyi.
- **Abel Prize** with Louis Nirenberg for his work on nonlinear partial differential equations.

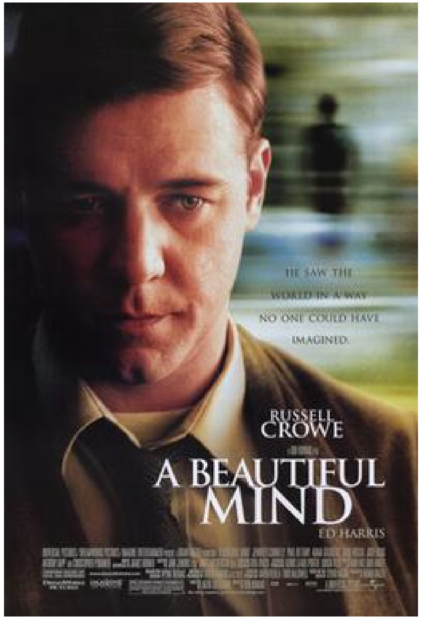


Nash in 2006.

Reference: https://en.wikipedia.org/wiki/John_Forbes_Nash_Jr.

A classic scene of “A Beautiful Mind”

- https://www.youtube.com/watch?v=2d_dtTZQyUM



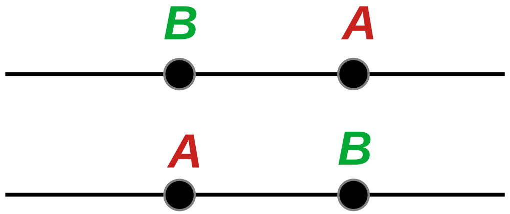
Starring: Russel Crowe

Before introducing **Nash Equilibria**...

- Let’s play around several “games” first.

Number Guessing

- Let's say I have chosen a secret number ***A*** in my mind, which is among 1 and 100.
- Please guess it by a number ***B***.
- If $B < A$, I will tell you "Larger, please".
- If $B > A$, I will tell you "Smaller, please".



- How many times do you think you can find out this secret number?

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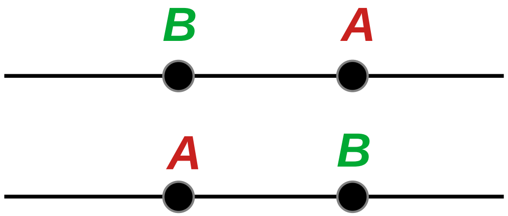
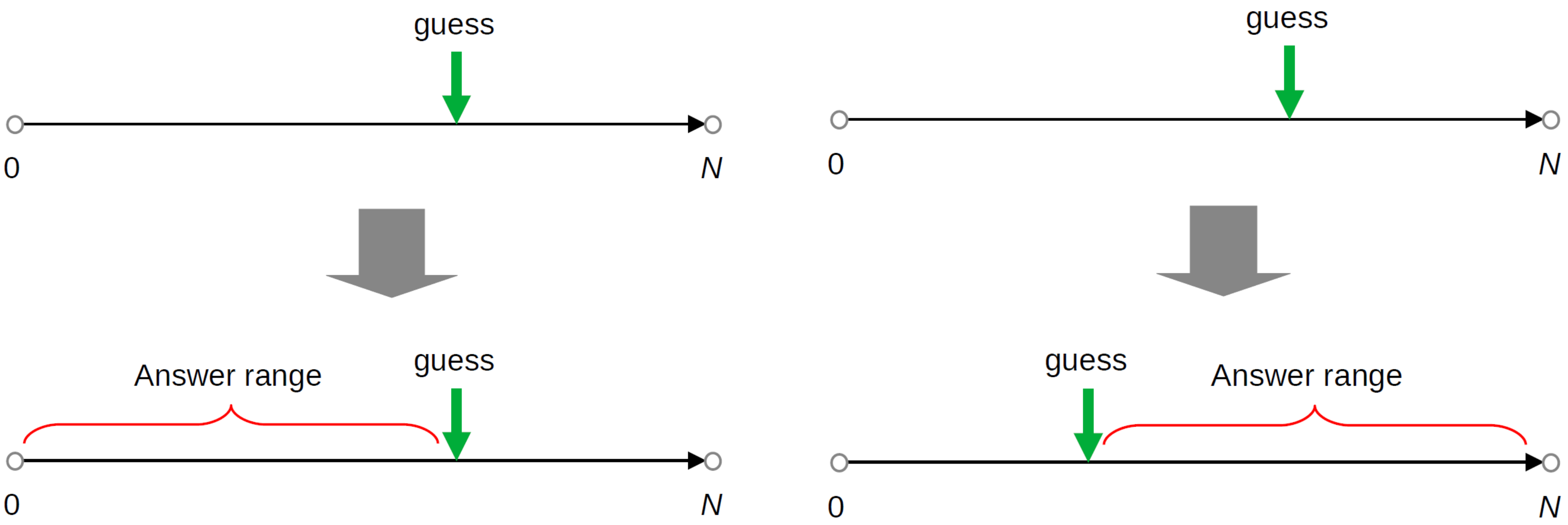


- How many times do you think you can find out this secret number? **Let's play to feel the strategic behaviors.**

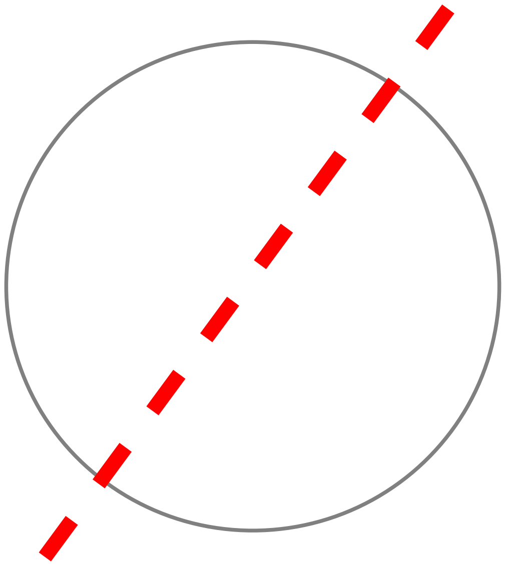
Adversarial Number Guessing

- The **demo** code.



Envy-Free Cake-Cutting

- Children wants everything to be FAIR.
- Actually, in their world, nothing is FAIR…… lol



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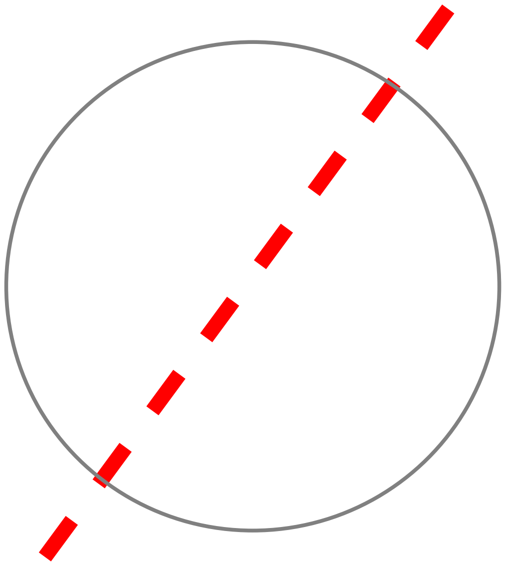
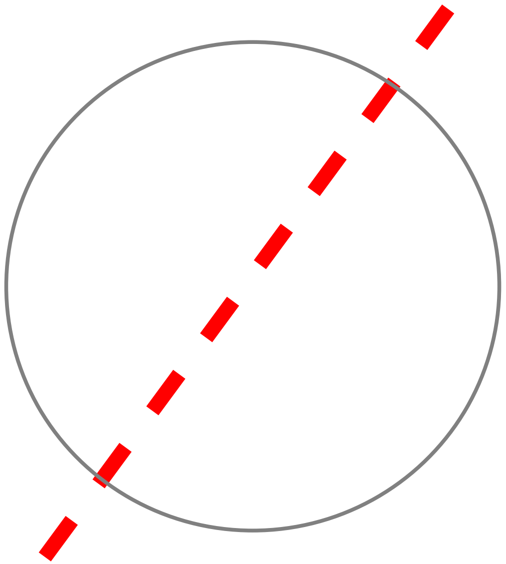
- Let’s say we want two kids to share a cake.



Envy-Free Cake-Cutting

- Children wants everything to be FAIR.
- Actually, in their world, nothing is FAIR…… lol
- Let's say we want two kids to share a cake.
- Can you propose a way of cutting a cake so that two kids share a cake so that **no one envies the other?**



Prisoners’ Dilemma

- It was originally framed by Merrill Flood and Melvin Dresher in 1950.
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source

Prisoners' Dilemma

- It was originally framed by Merrill Flood and Melvin Dresher in 1950.
- Let's say there are two guys, ***A*** and ***B***, who broke into a luxury store and stole a treasure.
- They had hided the treasure before the police caught them.
- They were kept in two separated rooms.
  - That means, they cannot communicate with each other…
- Each of them was offered two choices: **Denial** or **confession**.

Prisoners' Dilemma

- They were told that:

Prisoners’ Dilemma

- They were told that:
  - If both of them deny the fact of stealing the treasure, they will **BOTH** be sentenced in prison for **one** month.
  - If one of them confesses while the other one denies, the former will be set **FREE** while the latter will be sentenced in prison for **9** months.
  - If both confess, then they will both get **6** months in prison.
    - Because the police officers have got their images from the monitor...

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    - Because the police officers have got their images from the monitor…

- In your opinion, what should they do?
  - They cannot communicate, and they must make their decisions simultaneously.

Prisoners’ Dilemma

- We can use a “matrix” to formulate this game.
- Two **players**, two **actions** for each.
- If you are criminal *A*, what will you do?
- What’s the **solution** (outcome)?

Criminal *B*

Criminal *A*

	Denial	Confess
Denial	−1, −1	−9, 0
Confess	0, −9	−6, −6

Prisoners' Dilemma

- **Dominant strategy?**

- **Socially inefficient.**
  - **Why is it inefficient?**

- **Price of Anarchy (PoA).**

		Criminal *B*	
		Denial	Confess
Criminal *A*	Denial	−1, −1	−9, 0
	Confess	0, −9	−6, −6

Bach or Stravinsky (BoS)

- A historical two-player game.
  - The battle of sexes (in *Games and Decisions* by Luce and Raiffa, 1957).
  - Say Amy and Bob want to pick a concert to go to.

Bach or Stravinsky (BoS)

- A historical two-player game.
  - The battle of sexes (in *Games and Decisions* by Luce and Raiffa, 1957).
  - Say Amy and Bob want to pick a concert to go to.
  - Both prefer to go together than to go home.
  - However, Amy prefers Bach while Bob prefers Stravinsky.

Bach or Stravinsky (BoS)

- What are the SOLUTIONS of the game?
- Is there any **dominant** strategy for either Amy or Bob?

		Bob	
		Bach	Stravinsky
Amy	Bach	2, 1	0, 0
	Stravinsky	0, 0	1, 2

↑

The matrix form

Battle of Sexes (BoS)

- What are the SOLUTIONS of the game?
- Is there any **dominant** strategy for either Amy or Bob?

		Bob	
		Bach	Baseball Game
Amy	Movie	2, 1	0, 0
	Baseball Game	0, 0	1, 2

The matrix form

Matching Pennies

- Two players, playing a game by throwing a penny.
- Both ‘heads’ or both ‘tails’: player 1 keeps both pennies.
- Otherwise, player 2 keeps both pennies.

Matching Pennies

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The matrix form ➡

		Player 2	
		head	tail
Player 1	head	1, −1	−1, 1
	tail	−1, 1	1, −1

Matching Pennies

- **Zero-sum**?
- Do dominant strategies exist?
- What are the solutions?

		Player 2	
		head	tail
Player 1	head	1, −1	−1, 1
	tail	−1, 1	1, −1

Rock-Scissors-Paper Game

rock

scissors

paper

	Player 2			
		rock	scissors	paper
Player 1	rock	0, 0	1, −1	−1, 1
	scissors	−1, 1	0, 0	1, −1
	paper	1, −1	−1, 1	0, 0

Rock-Scissors-Paper Game

- **Zero-sum**?
- **Dominant strategies**?
- Any **solutions**?

Player 2

Player 1

	rock	scissors	paper
rock	0, 0	1, −1	−1, 1
scissors	−1, 1	0, 0	1, −1
paper	1, −1	−1, 1	0, 0

Mixed Strategies

- What we have discussed about are all **pure strategies**.
  - A deterministic action.

Mixed Strategies

- What we have discussed about are all **pure strategies**.
  - A deterministic action.
- What is a **mixed strategy**?

Mixed Strategies

- Like this?
  - Nine-headed Dragon Strike.
- Or like this?
  - Man of many pitches.
- For a portfolio manager in a hedge fund:
  - Portfolio weighting.

Back to the Game of Matching Pennies

- Setting the weights?

		Player 2	
		head	tail
Player 1	head	1, −1	−1, 1
	tail	−1, 1	1, −1

Back to the Game of Matching Pennies

- Setting the weights? $0 < \epsilon, \rho < 1$

Player 2

		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1-\rho$
		ϵ	$1-\epsilon$	

Back to the Game of Matching Pennies

- Setting the weights? $0 < \epsilon, \rho < 1$
- The expected utility of player 1 playing ‘head’:

$$f = 1 \cdot \epsilon + (-1) \cdot (1 - \epsilon)$$

- The expected utility of player 1 playing ‘tail’:

$$g = -1 \cdot \epsilon + 1 \cdot (1 - \epsilon)$$

Player 2

		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1 - \rho$
		ϵ	$1 - \epsilon$	

An intuitive definition of a **Nash equilibrium**

- A state such that no player can increase her expected payoff (profit, gain, advantage, money, etc.) by a **unilateral** deviation.

- **Nash's Theorem:**

  Every **finite** game (a finite number of players, each has a finite number of pure strategies) has **at least one** Nash equilibrium.

Back to the Game of Matching Pennies

- Setting the weights? $0 < \epsilon, \rho < 1$
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- The expected utility of player 1 playing ‘tail’:

$$g = 1 \cdot \epsilon + (-1) \cdot (1 - \epsilon)$$

- What if $f \neq g$?

		Player 2		
		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1 - \rho$
		ϵ	$1 - \epsilon$	

Back to the Game of Matching Pennies

- Setting the weights? $0 < \epsilon, \rho < 1$
- The expected utility of player 1 playing ‘head’:

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- The expected utility of player 1 playing ‘tail’:

$$g = -1 \cdot \epsilon + 1 \cdot (1 - \epsilon)$$

- What if $f \neq g$?

Consider Player 1’s expected utility: $\rho \cdot f + (1 - \rho) \cdot g$

Player 2

		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1 - \rho$
		ϵ	$1 - \epsilon$	

Back to the Game of Matching Pennies

- Setting the weights? $0 < \epsilon, \rho < 1$
- The expected utility of player 1 playing ‘head’:

$$f = 1 \cdot \epsilon + (-1) \cdot (1 - \epsilon)$$

- The expected utility of player 1 playing ‘tail’:

$$g = -1 \cdot \epsilon + 1 \cdot (1 - \epsilon)$$

- **Solving** $f = g \quad \Rightarrow \quad \epsilon = 0.5.$

  Now it’s your turn to solve ρ.

Player 2

		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1 - \rho$
		ϵ	$1 - \epsilon$	

Back to the Game of Matching Pennies

- Take your time.

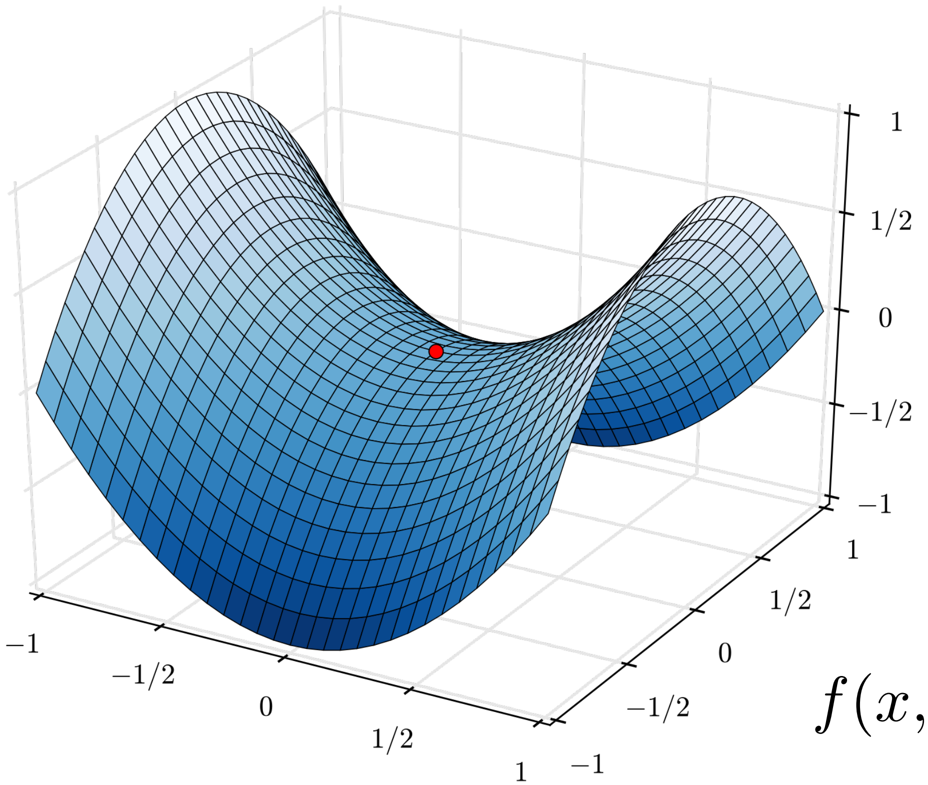
- So we just proved that the game has a kind of solution:

“Mixed-Strategy Nash Equilibrium”.

Player 2

		head	tail	
Player 1	head	1, −1	−1, 1	ρ
	tail	−1, 1	1, −1	$1-\rho$
		ϵ	$1-\epsilon$	

Saddle point illustration



$$f(x, y) = x^2 - y^2.$$

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- A state such that no player can increase her expected payoff (profit, gain, advantage, money, etc.) by a **unilateral** deviation.

- **Nash's Theorem:**

  Every **finite** game (a finite number of players, each has a finite number of pure strategies) has **at least one** Nash equilibrium.

- The concept of **best responses** & **mixed strategies**.

Back to the classic scene of “A Beautiful Mind”

- https://www.youtube.com/watch?v=2d_dtTZQyUM

- Do you observe anything strange or anything wrong?
  - https://www.youtube.com/watch?v=DTcmmD_MWas

An Easy Exercise

- Please find out a mixed-strategy Nash equilibrium of the rock-scissors-paper game.

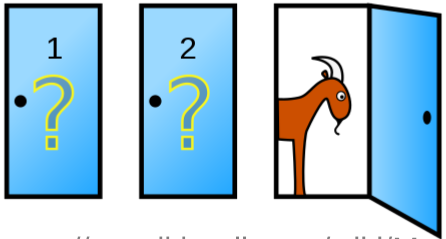
Player 2

		rock	scissors	paper
Player 1	rock	0, 0	1, −1	−1, 1
	scissors	−1, 1	0, 0	1, −1
	paper	1, −1	−1, 1	0, 0

The Monty Hall Problem

- From an American TV show *Let’s Make a Deal* hosted by Monty Hall.

Suppose you're on a game show, and you're given the choice of three doors: Behind one door is a car; behind the others, goats. You pick a door, say No. 1, and the host, who knows what's behind the doors, opens another door, say No. 3, which has a goat. He then says to you, "Do you want to pick door No. 2?" **Is it to your advantage to switch your choice?**



https://en.wikipedia.org/wiki/Monty_Hall_problem