Week 1: Why do we need game theory,

…and what does it tell us?

- Focus on basic concepts

- Focus on basic concepts
- Ideas, philosophy,

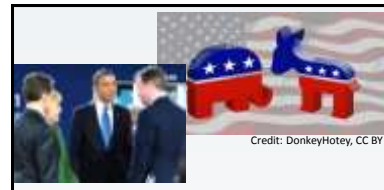
- Focus on basic concepts
- Ideas, philosophy, history

- Focus on basic concepts
- Ideas, philosophy, history

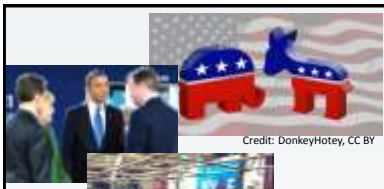
…hidden behind mathematical models

- 1.1 What is game theory?

Credit: DonkeyHotey, CC BY



Credit: DonkeyHotey, CC BY



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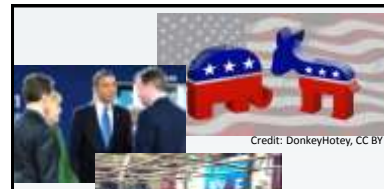

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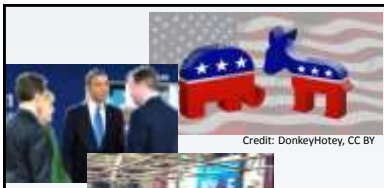
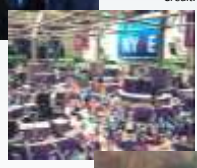


Credit: DonkeyHotey, CC BY



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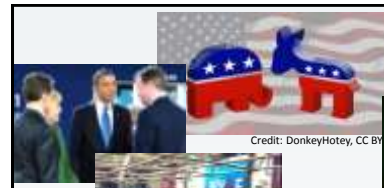

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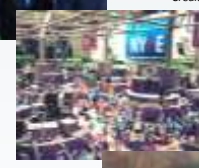

Credit: Cacophony, CC BY-SA 3.0

“Social” problem

“Social” problem

You interact with others

“Social” problem

You interact with others

What is best for you depends on what others do

“Social” problem

You interact with others

What is best for you depends on what others do

Strategic Situation

Credit: DonkeyHotey, CC BY

Credit: Cacophony, CC BY-SA 3.0

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What is best for you depends on what others do

Strategic Situation

"Social" problem

You interact with others

What is best for you depends on what others do

Strategic Situation

Game theory constructs mathematical models to examine how people behave in strategic situations

Sorry, Game Theory is not about your favorite video games....

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Question 1: What determines the policies of the two parties?

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Question 2: What happens to the traffic flows if we construct a new bypass?

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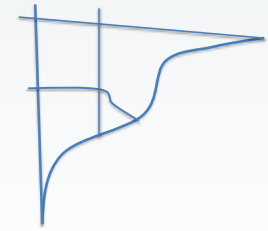
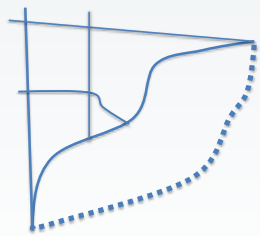


Question 2: What happens to the traffic flows if we construct a new bypass?



Game theory

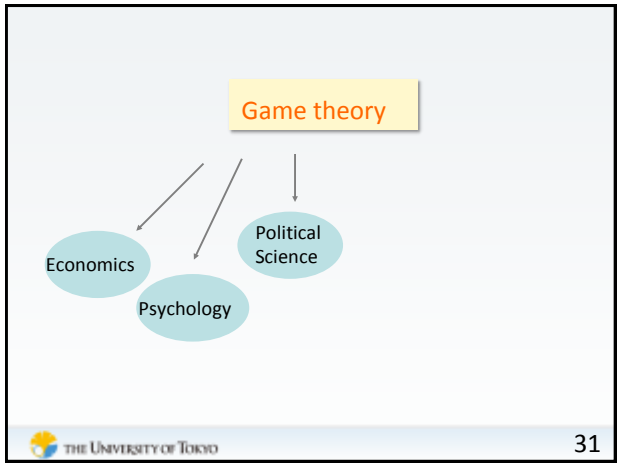
Game theory

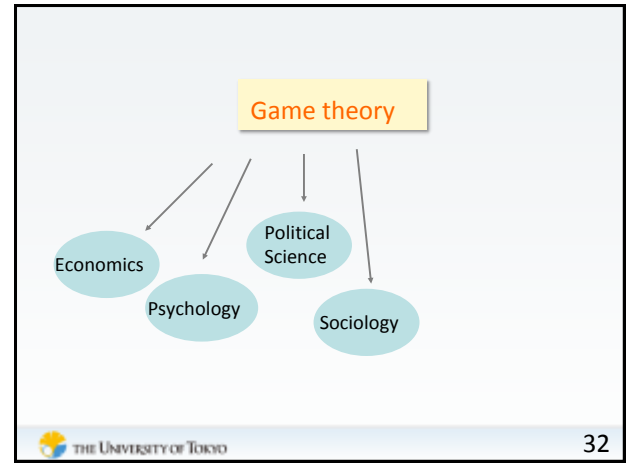
Economics

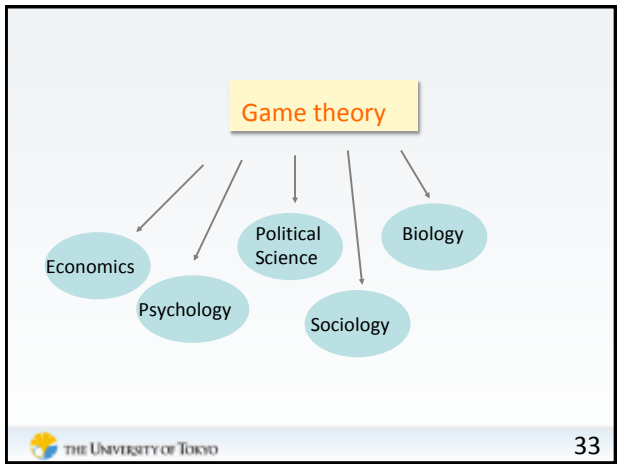
Game theory

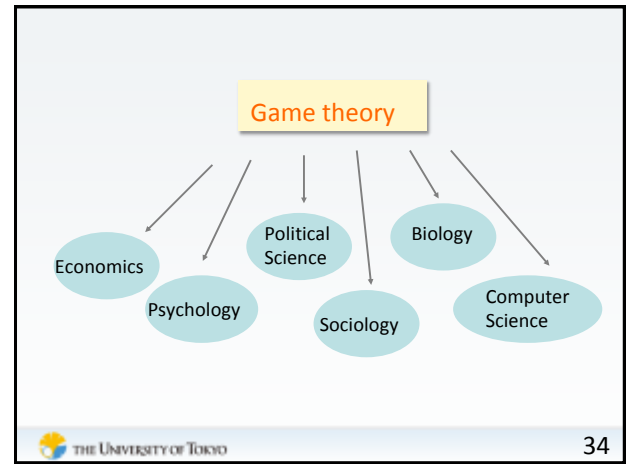
Economics

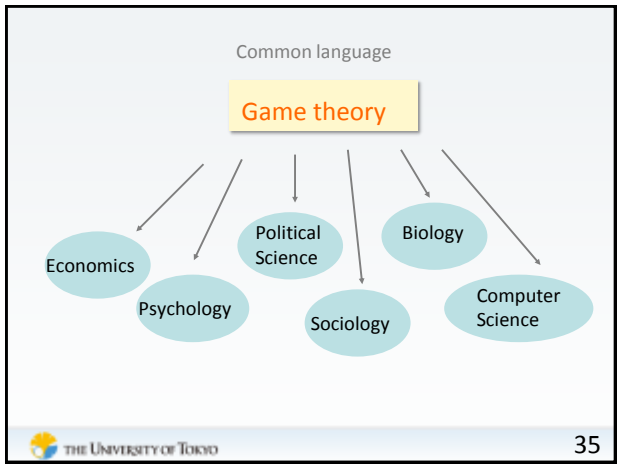
Psychology



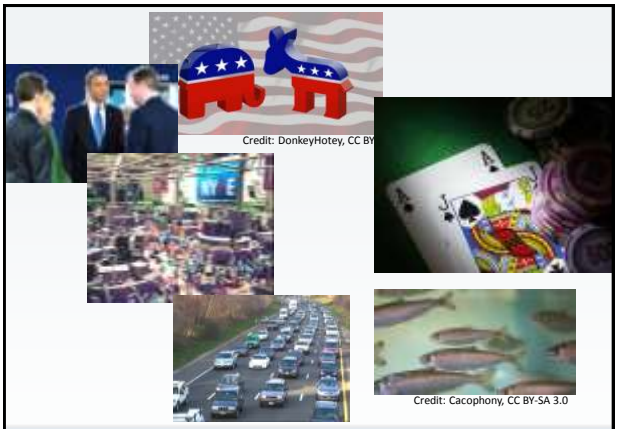






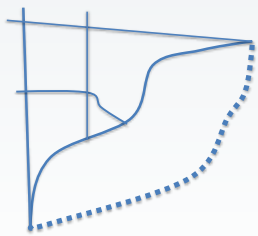


1.2 Modelling social problems as a "game"

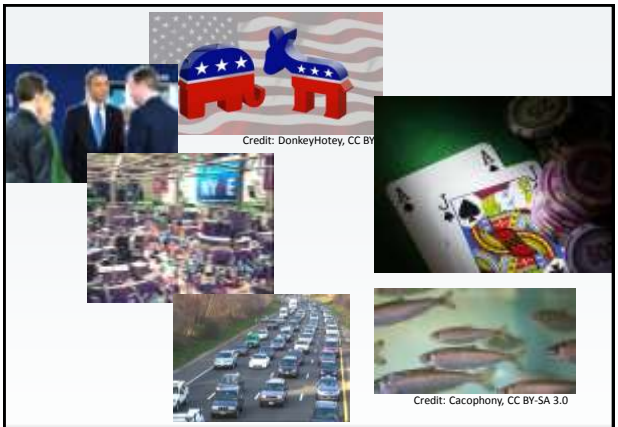


Question 1: What determines the policies of the two parties?

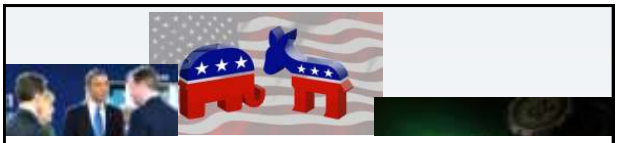
Question 2: What happens to the traffic flows if we construct a new bypass?



"Ad-hoc" approach



(a) Individuals try to do their best against others



(a) Individuals try to do their best against others

(b) under a certain set of rules

Credit: Cacophony, CC BY-SA 3.0

(a) Individuals try to do their best against others

(b) under a certain set of rules

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Social problems can be formulated as a mathematical model.

(a) Individuals try to do their best against others

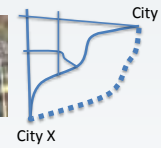
(b) under a certain set of rules

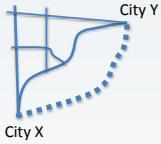
Social problems can be formulated as a mathematical model.

"game"

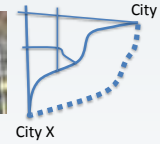
Question 1: What determines the policies of the two parties?

Credit: DonkeyHotey, CC BY

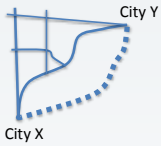


(1) Players

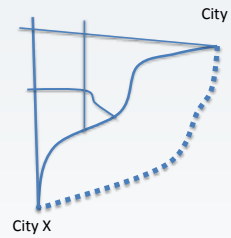



(1) Players = drivers commuting from City X to City Y

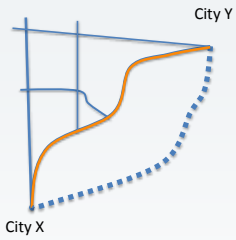



(1) Players = drivers commuting from City X to City Y

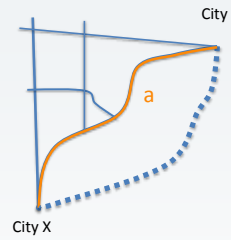
(2) Strategies of each player

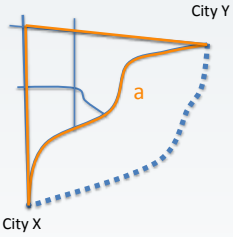
(2) Strategies of each player

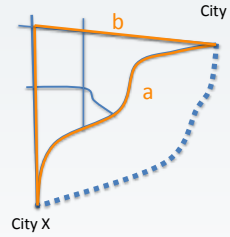
(2) Strategies of each player

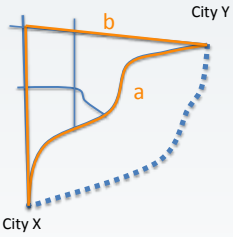
(2) Strategies of each player



(2) Strategies of each player

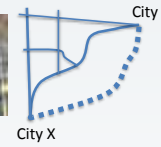


(2) Strategies of each player



(2) Strategies of each player

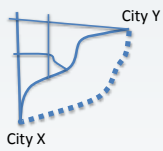
{Route a, Route b,….}



(1) Players = drivers commuting from City X to City Y

(2) Strategies of each player

{Route a, Route b,….}

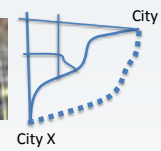


(1) Players = drivers commuting from City X to City Y

(2) Strategies of each player

{Route a, Route b,….}

(3) Payoff of each player



(1) Players = drivers commuting from City X to City Y

(2) Strategies of each player

{Route a, Route b,….}

(3) Payoff of each player

= – (traveling time)

(a) Individuals try to do their best against others

(b) under a certain set of rules

Credit: Cacophony, CC BY-SA 3.0

Credit: Donkey Hotey, CC BY

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Is there a general theory?

Credit: Donkey Hotey, CC BY

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Is there a general theory?

Game
(1) Players
(2) Strategies
(3) Payoffs

Credit: Donkey Hotey, CC BY

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Is there a general theory?

Game
(1) Players
(2) Strategies
(3) Payoffs

General “Solution” ?

“unified” approach

Credit: Donkey Hote

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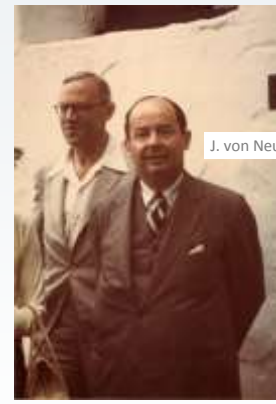
Is there a “governing principle”?

(a) Individuals try to do their best against others

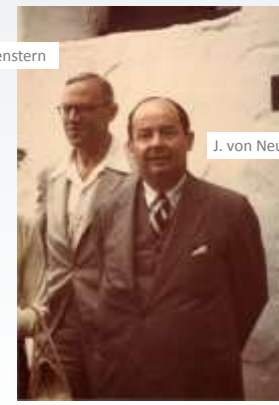
(b) under a certain set of rules



J. von Neumann

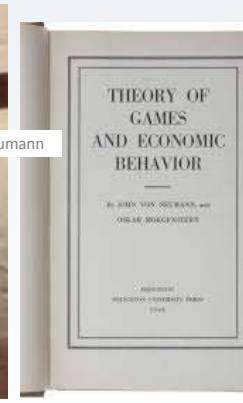
O. Morgenstern

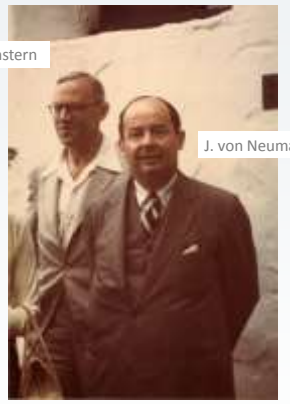
J. von Neumann



O. Morgenstern

J. von Neumann





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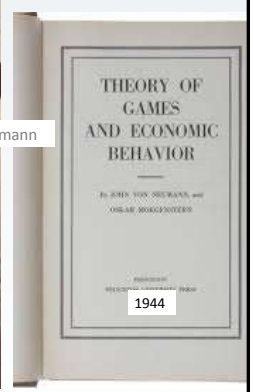


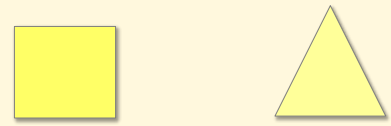
- 1.3 In search for the governing principle

Individuals try to do their best against others

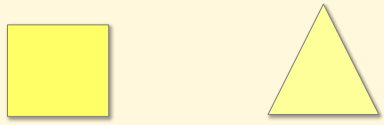
Individuals try to do their best against others

Basic Idea

Basic Idea

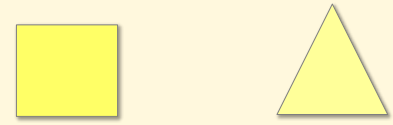


Basic Idea



Better

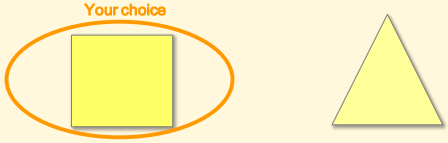
Basic Idea



Better Worse

Basic Idea

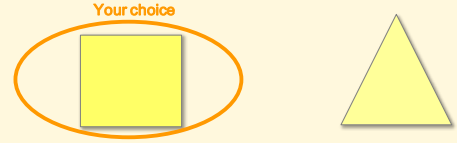
Your choice



Better Worse

Basic Idea

Your choice

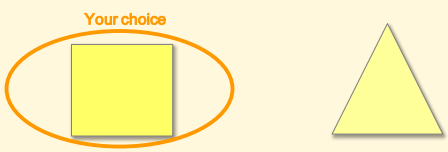


Better Worse

Not as perfect or accurate as Newton's law….

Basic Idea

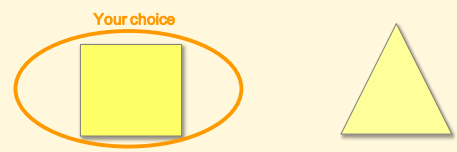
Your choice



Better Worse

Basic Idea

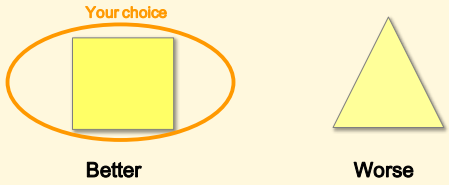
Your choice



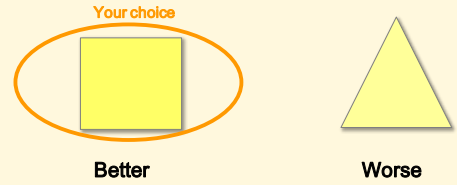
Better Worse

… but it captures an important driving force of human behavior.

Basic Idea

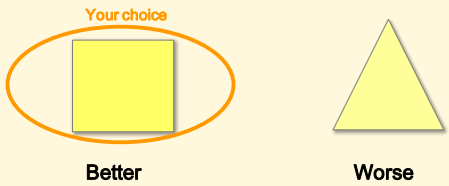


Basic Idea



"Rationality"

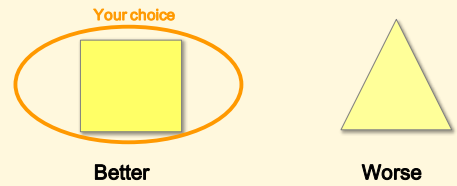
Basic Idea



Payoff = 2

"Rationality"

Basic Idea

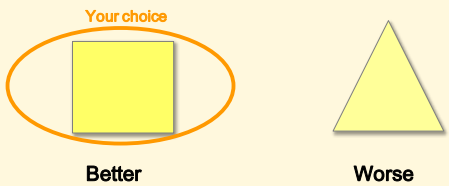


Payoff = 2

Payoff = 1

"Rationality"

Basic Idea



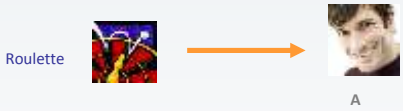
Payoff = 2

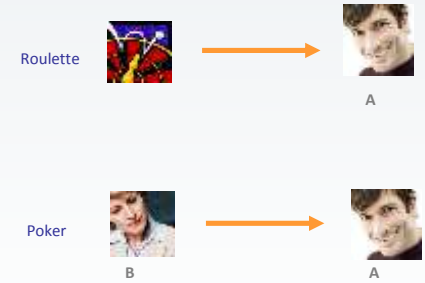
Payoff = 1

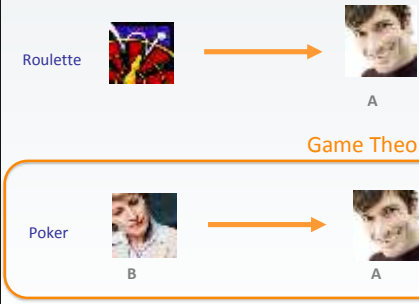
"Rationality"

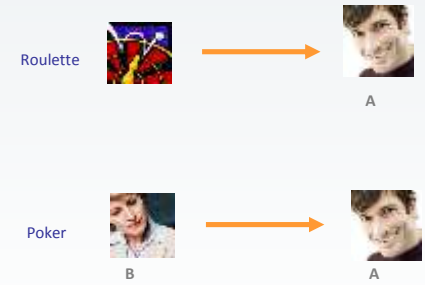
Maximizing your payoff

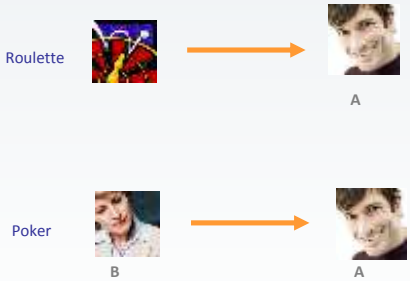
How far can we go with that basic idea?

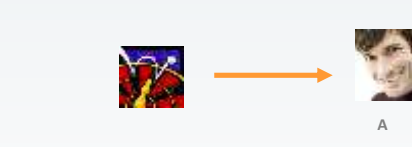

Roulette
A


Roulette
A
Poker
B
A


Roulette
A
Game Theory
Poker
B
A


Roulette
A
Poker
B
A


Roulette
A
Poker
B
A
Substantially
more complex


A


Behavior is given

A


Behavior is given

A

A's behavior can be described by a simple math problem


Behavior is given

A

A's behavior can be described by a simple math problem

Maximization of his payoff

Poker


B

A

Poker


B

A

Behavior is not given

Poker

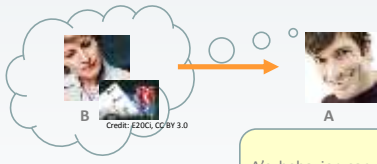

B

A

Behavior is not given

A's behavior ?

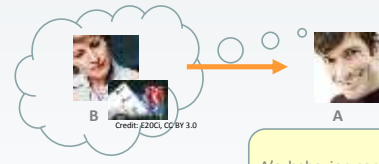
A's prediction or belief



A's prediction or belief

A's behavior can be described by a simple math problem

Maximization of his payoff

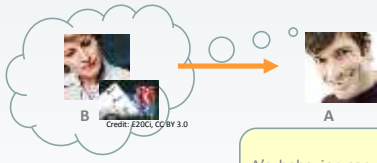


A's prediction or belief

A's behavior can be described by a simple math problem

Maximization of his payoff

Is this the end of the story？



A's prediction or belief

A's behavior can be described by a simple math problem

Maximization of his payoff

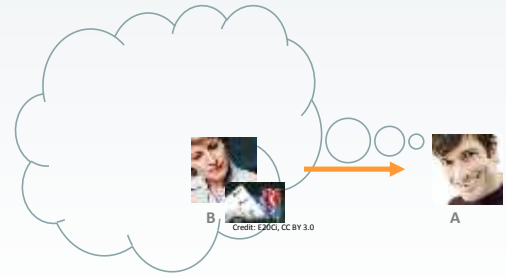
No!

Unlike roulette, B is not choosing her behavior mechanically.

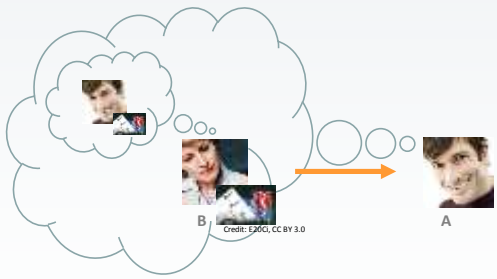
Unlike roulette, B is not choosing her behavior mechanically.

To better predict B's behavior, we need to examine what she is thinking about.

A deeper strategic thought

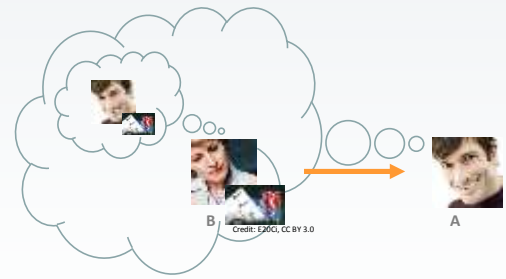


A deeper strategic thought

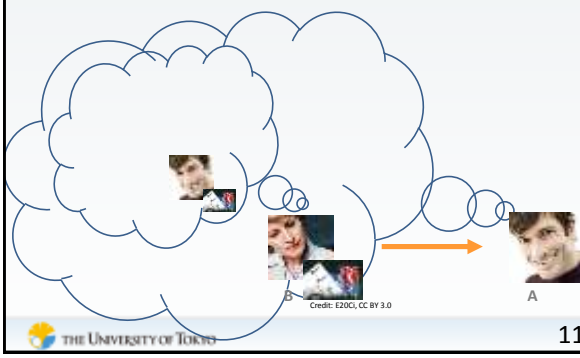


A deeper strategic thought

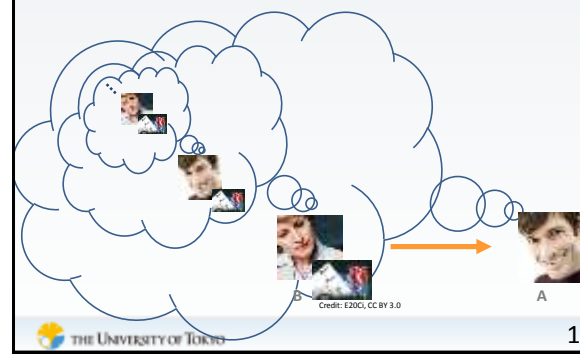
A's belief about B's belief



We can go further and further ….

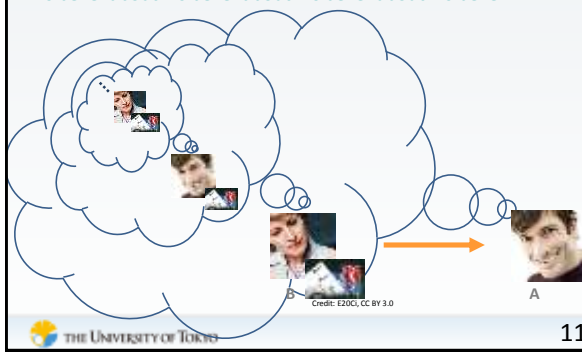


We can go further and further ….



We can go further and further ….

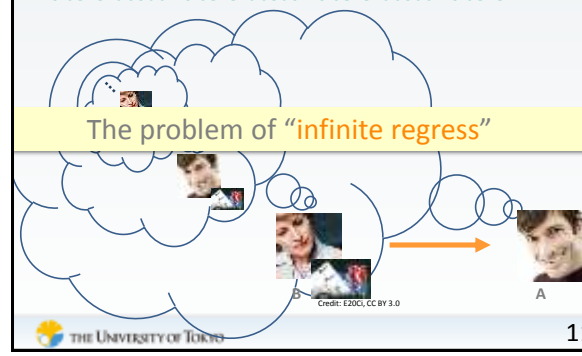
A's belief about B's belief about A's belief about B's belief ……



We can go further and further ….

A's belief about B's belief about A's belief about B's belief ……

The problem of "infinite regress"



Rationality alone fails to pin down individuals' behavior in social problems.

Simple math model of maximization

Rationality alone fails to pin down individuals' behavior in social problems.

Simple math model of maximization

Rationality alone fails to pin down individuals' behavior in social problems.

This is the reason why we need game theory.

Simple math model of maximization

Rationality alone fails to pin down individuals' behavior in social problems.

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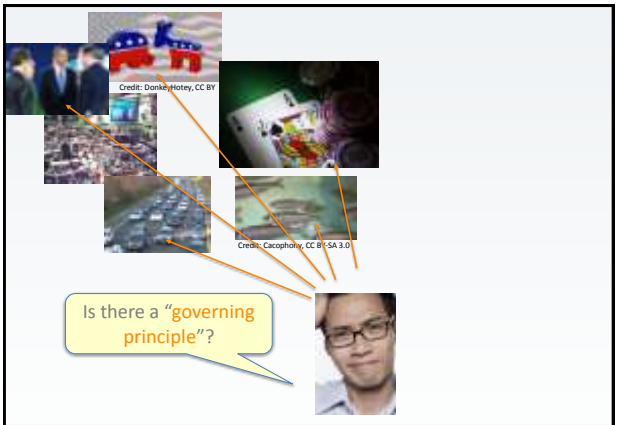
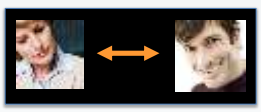


1.4 Concerns about a mathematical theory of human behavior

Prediction by mathematical formula

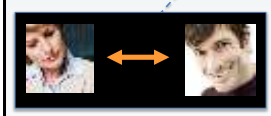
Credit: MichaelMaggs, CC BY-SA 3.0

Prediction by mathematical formula



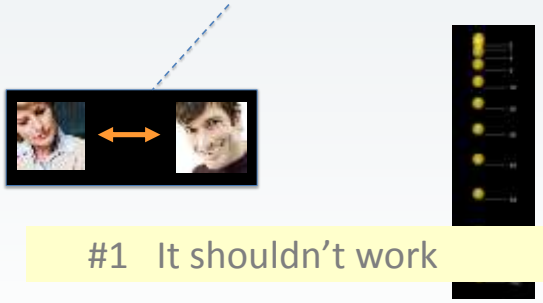
Credit: MichaelMaggs, CC BY-SA 3.0

Prediction by mathematical formula



Credit: MichaelMaggs, CC BY-SA 3.0

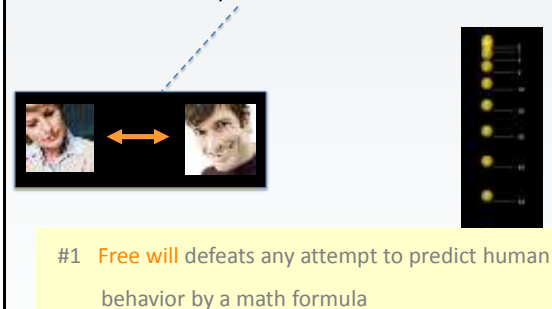
Prediction by mathematical formula



#1 It shouldn't work

Credit: MichaelMaggs, CC BY-SA 3.0

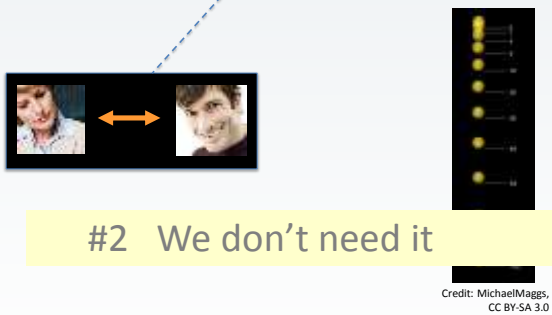
Prediction by mathematical formula



#1 Free will defeats any attempt to predict human behavior by a math formula

CC BY-SA 3.0

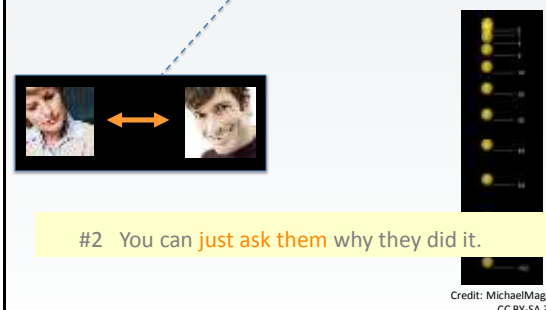
Prediction by mathematical formula



#2 We don't need it

Credit: MichaelMaggs, CC BY-SA 3.0

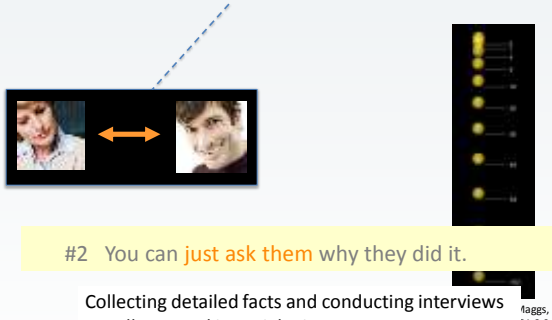
Prediction by mathematical formula



#2 You can just ask them why they did it.

Credit: MichaelMaggs, CC BY-SA 3.0

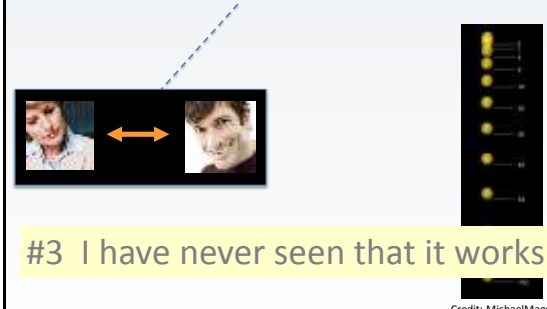
Prediction by mathematical formula



#2 You can just ask them why they did it.

Collecting detailed facts and conducting interviews are all we need in social sciences

Prediction by mathematical formula



#3 I have never seen that it works.

Credit: MichaelMaggs, CC BY-SA 3.0

Sometime around 1939, a mathematician teased an economist….

Stan Ulam

Stan Ulam

Paul Samuelson

Name me one proposition in all of the social sciences which is **both true and non-trivial**.

Stan Ulam

Paul Samuelson

Name me one proposition in all of the social sciences which is **both true and non-trivial**.

Stan Ulam

……

Paul Samuelson

Name me one proposition in all of the social sciences which is **both true and non-trivial**.

Stan Ulam

……

This was a test that I always failed.

Paul Samuelson

(Valid) concerns about game theory

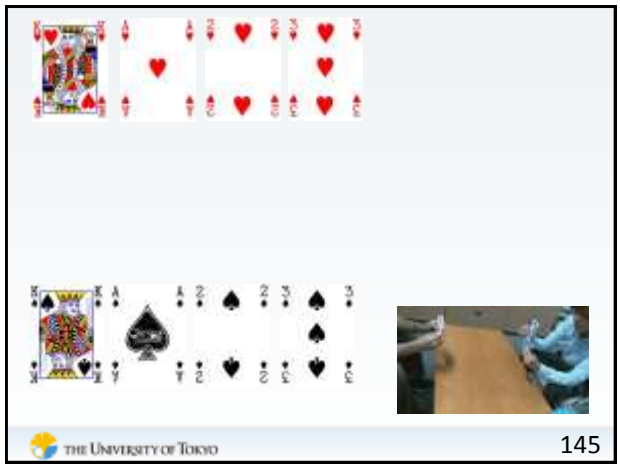
#1 Free will defeats any attempt to predict human behavior by a math formula

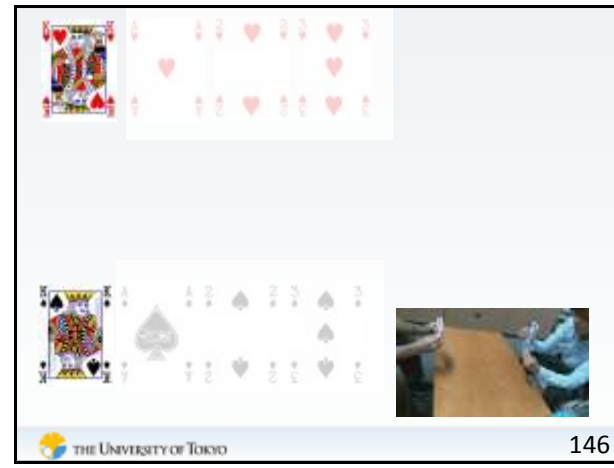
#2 You can just ask, “why did you do that?”

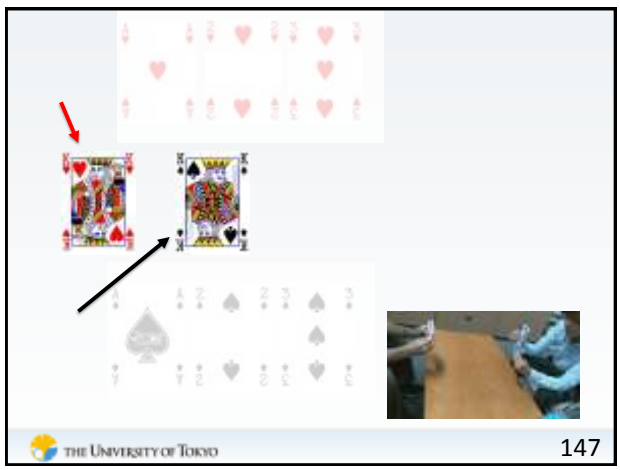
#3 I’ve never heard it works.

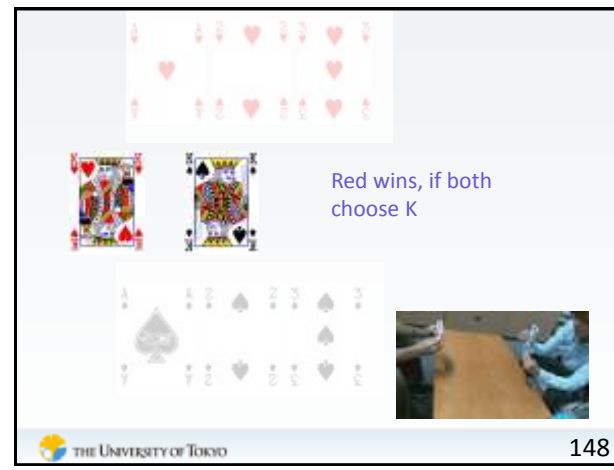
1.5 Let’s play a game

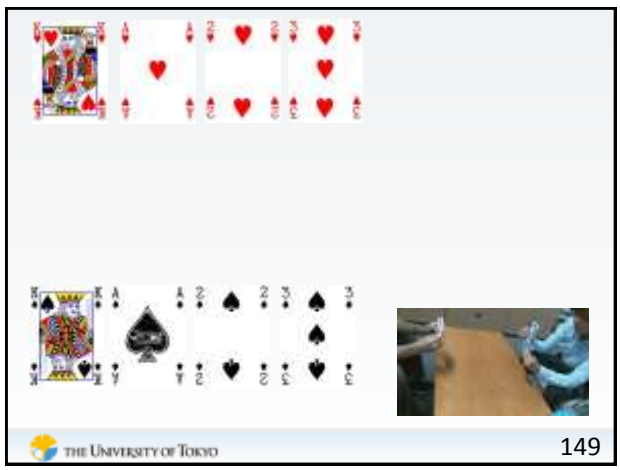
Each player carefully chooses one card and show it to the opponent (simultaneously)

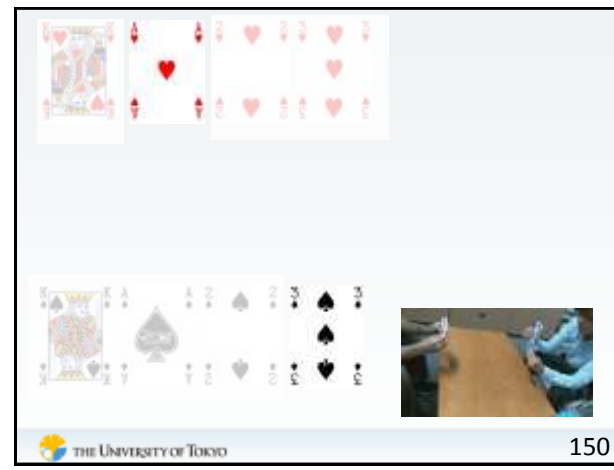


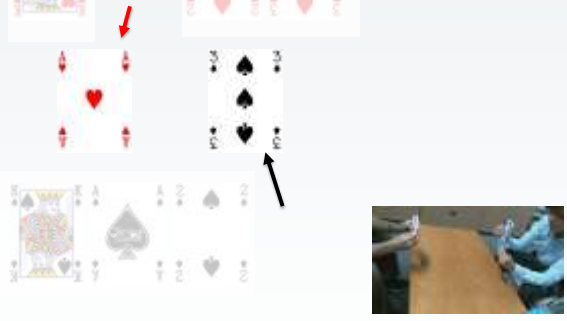




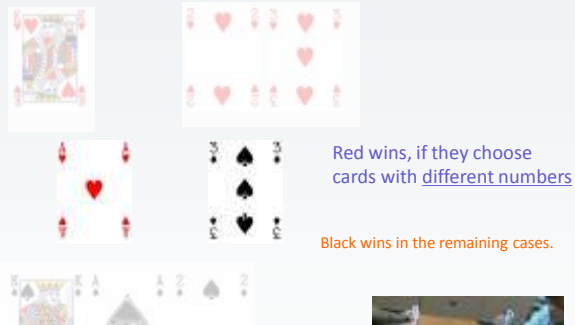

Red wins, if both
choose K







Red wins, if they choose cards with different numbers



Red wins, if they choose cards with different numbers

Black wins in the remaining cases.

Red player wins if …

Red player wins if …

- both choose K

Red player wins if …

- both choose K
- players choose cards with different numbers

Red player wins if …

- both choose K
- players choose cards with different numbers

such as  and 

Red player wins if …

- both choose K
- players choose cards with different numbers

such as  and 

Black player wins if …

Red player wins if …

- both choose K
- players choose cards with different numbers

such as  and 

Black player wins if …

- only one player chooses K

Red player wins if …

- both choose K
- players choose cards with different numbers

such as  and 

Black player wins if …

- only one player chooses K
- players choose cards with the same number

Red player wins if …

- both choose K
- players choose cards with different numbers

such as  and 

Black player wins if …

- only one player chooses K
- players choose cards with the same number

such as  and 

Who has an advantage,
Red or Black?

What is the winning rate of each player?

Any prediction about the cards they choose?

- 1.6 John Nash discovered the governing principle

Game theory was created by Neumann and Morgenstern in 1944, but even in 1950 the central problem was still open.

Is there a general theory?

Game
(1) Players
(2) Strategies
(3) Payoffs

General "Solution" ?

John Nash

Credit: Peter Badge, CC BY-SA 3.0

John Nash

Credit: Peter Badge, CC BY-SA 3.0

John Nash

This man is a genius.

Credit: Peter Badge, CC BY-SA 3.0

1994: Nobel prize in economics

Motion Picture: A Beautiful Mind

1994: Nobel prize in economics

Motion Picture: A Beautiful Mind

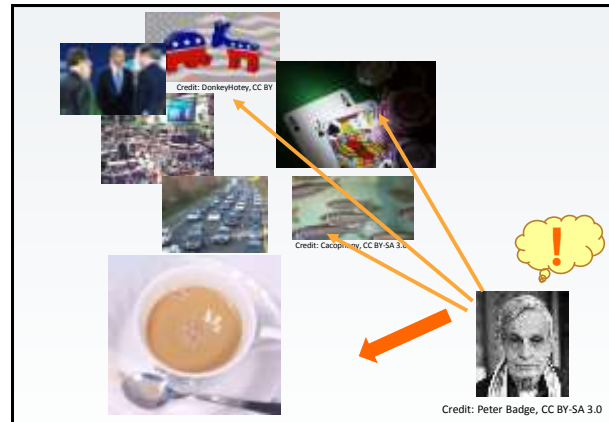
1994: Nobel prize in economics

Motion Picture: A Beautiful Mind

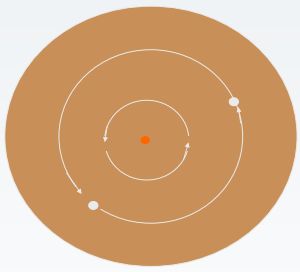
Credit: ©2001 Universal Studios and DreamWorks LLC. All Rights Reserved.

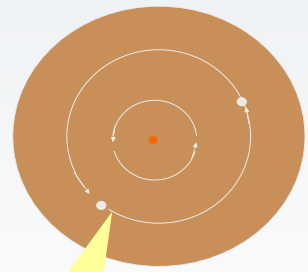
Credit: DonkeyHotey, CC BY

Credit: Peter Badge, CC BY-SA 3.0

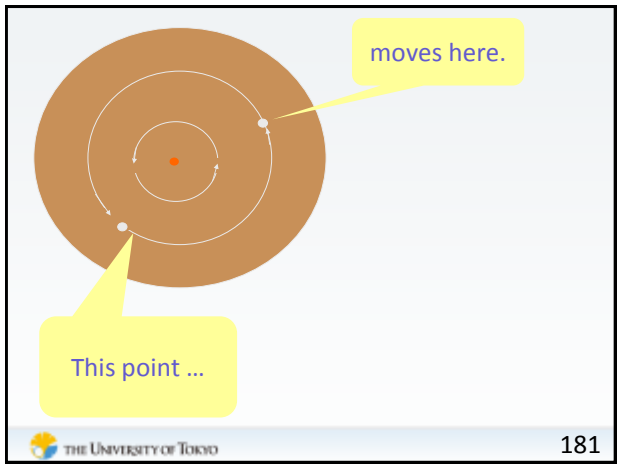


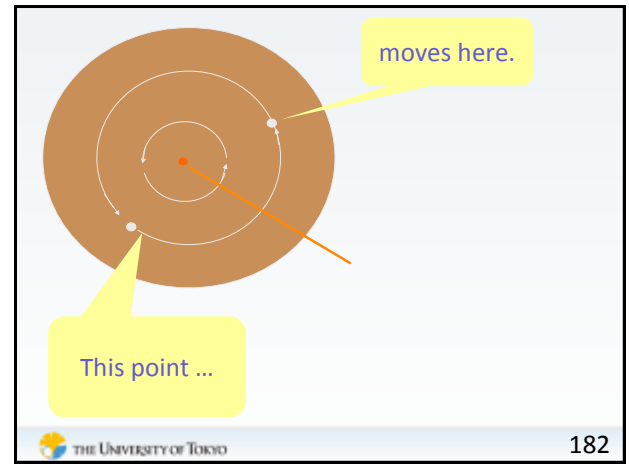
A vortex and human behavior…..why are they similar?

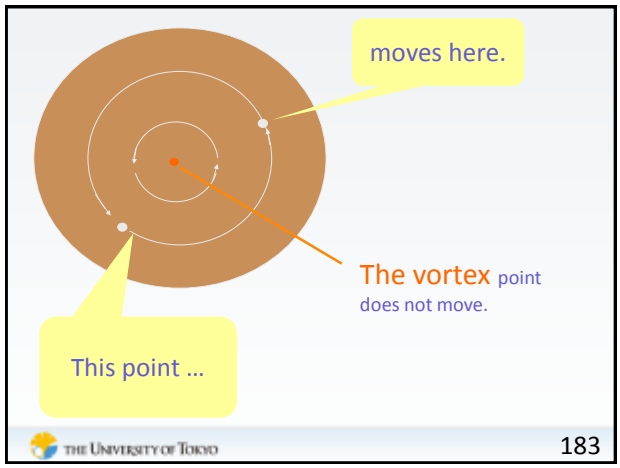




This point …







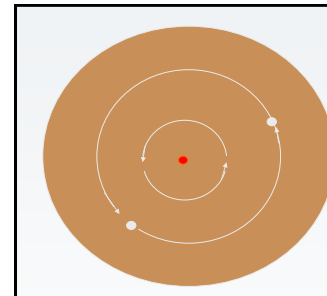
Suppose the surface of coffee represents

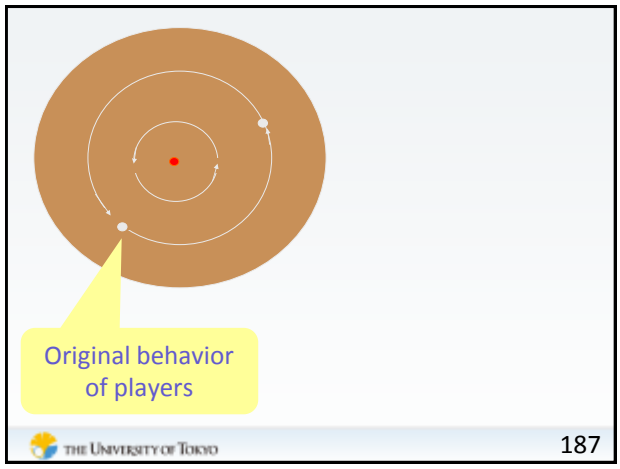
the set of possible human behavior.

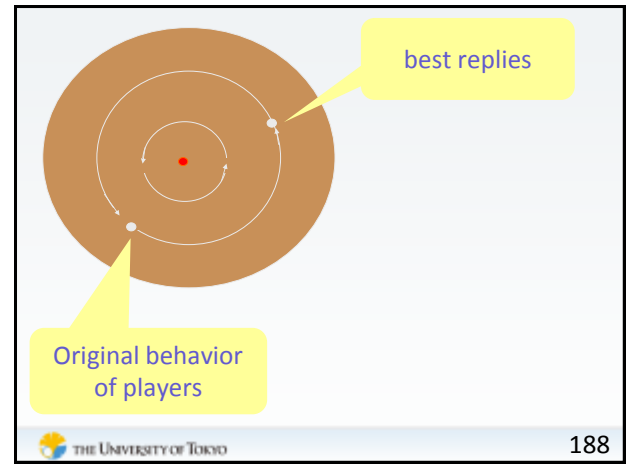
Suppose the surface of coffee represents

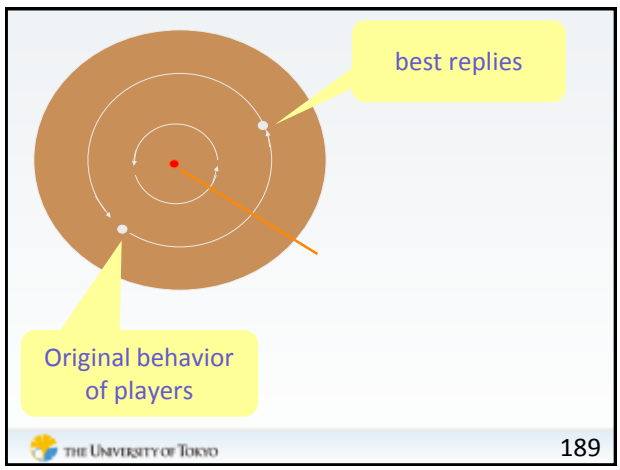
the set of possible human behavior.

This is really an ingenious idea of Nash!

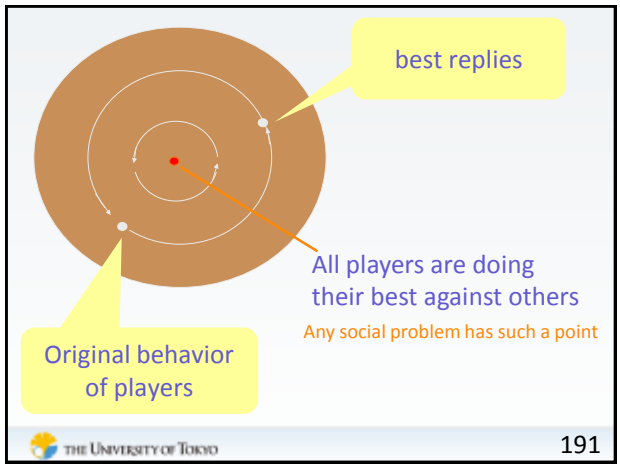


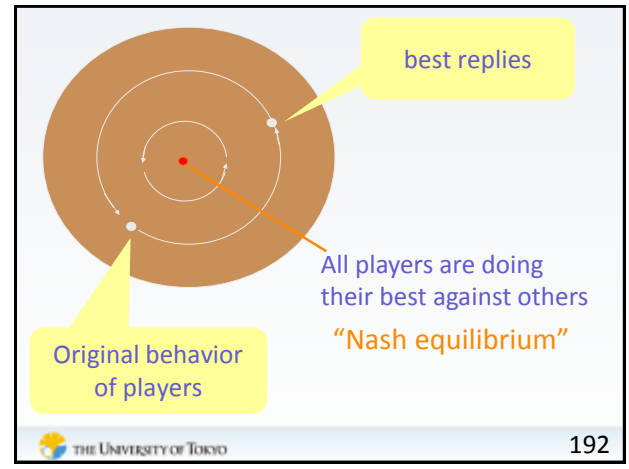

Original behavior
of players


best replies
Original behavior
of players


best replies
Original behavior
of players


best replies
All players are doing
their best against others
Original behavior
of players


best replies
All players are doing
their best against others
Any social problem has such a point
Original behavior
of players


best replies
All players are doing
their best against others
"Nash equilibrium"
Original behavior
of players

Nash discovered that every social problem has

a "stable point" where

Nash discovered that every social problem has

a "stable point" where

all individuals are doing their best against others

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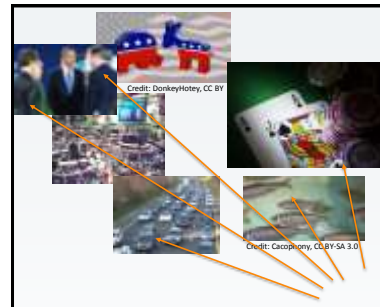
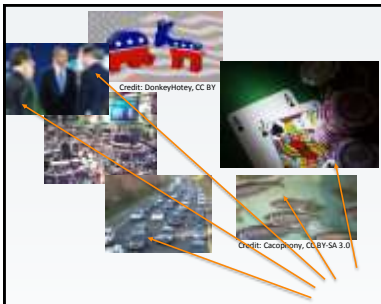
Nash equilibrium



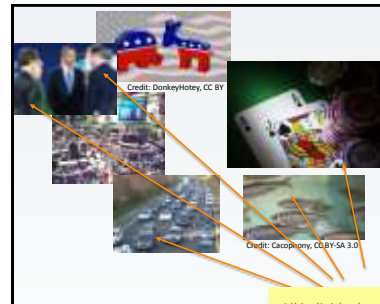
Game
(1) Players
(2) Strategies
(3) Payoffs

General "Solution"



Game
(1) Players
(2) Strategies
(3) Payoffs

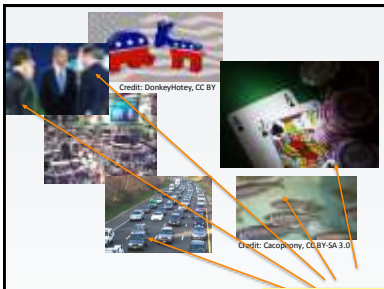
General "Solution"



Game
(1) Players
(2) Strategies
(3) Payoffs

General "Solution"

All individuals are doing their best against others



Game
(1) Players
(2) Strategies
(3) Payoffs

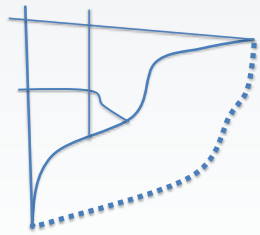
General "Solution"

All individuals are doing their best against others

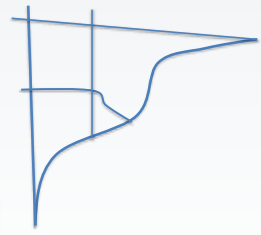
Nash equilibrium

1.7 Nash equilibrium

Question 2: What happens to the traffic flows if we construct a new bypass?



Question 2: What happens to the traffic flows if we construct a new bypass?



Nash equilibrium

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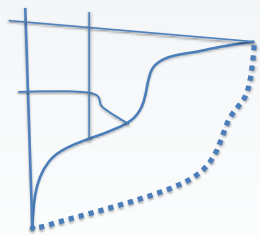
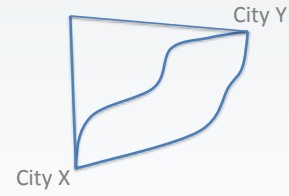


Nash equilibrium

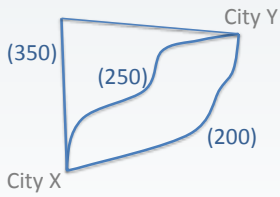
Traffic game

150 cars are commuting from X to Y



Traffic game

150 cars are commuting from X to Y



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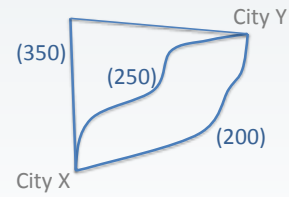

- Number in ( ) = Route length

Traffic game

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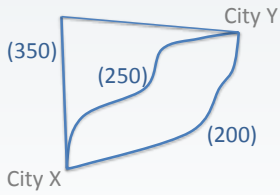
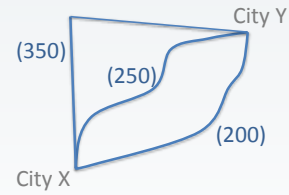


- Number in ( ) = Route length
- Traveling time = (Route length) + (number of cars on the Route)

Traffic game

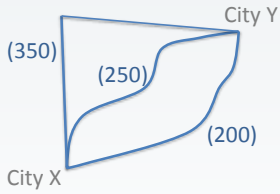
150 cars are commuting from X to Y



- Number in ( ) = Route length
- Traveling time = (Route length) + (number of cars on the Route)
- Payoff = – (traveling time)

Traffic game

150 cars are commuting from X to Y

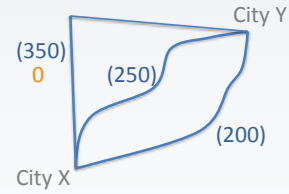


Nash equilibrium traffic

- Number in ( ) = Route length
- Traveling time = (Route length) + (number of cars on the Route)

Traffic game

150 cars are commuting from X to Y



Nash equilibrium traffic

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Traffic game

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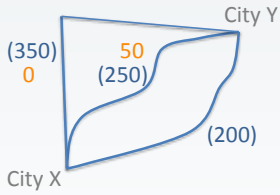

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Traffic game

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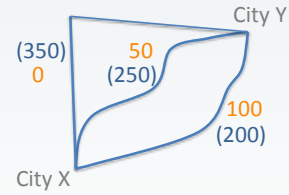

Nash equilibrium traffic

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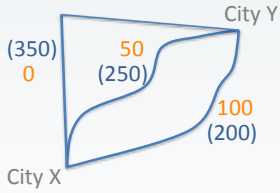
Traffic game

150 cars are commuting from X to Y

Traveling time



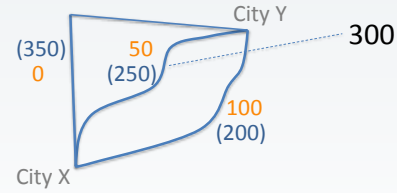
Nash equilibrium traffic

- Number in ( ) = Route length
- **Traveling time** = (Route length) + (number of cars on the Route)

Traffic game

150 cars are commuting from X to Y

Traveling time



Nash equilibrium traffic

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Traffic game

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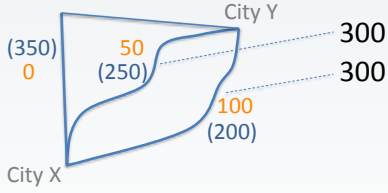
Traveling time



Nash equilibrium traffic

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Traffic game

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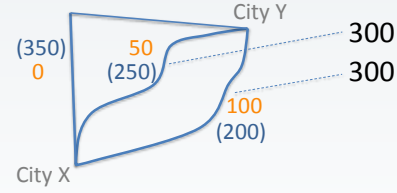
Traveling time

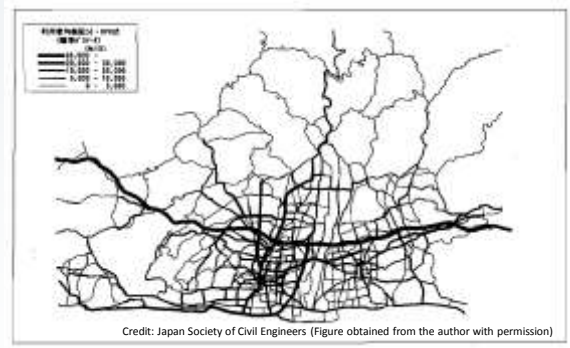


Nash equilibrium traffic

No one can save traveling time by changing his/her Route.

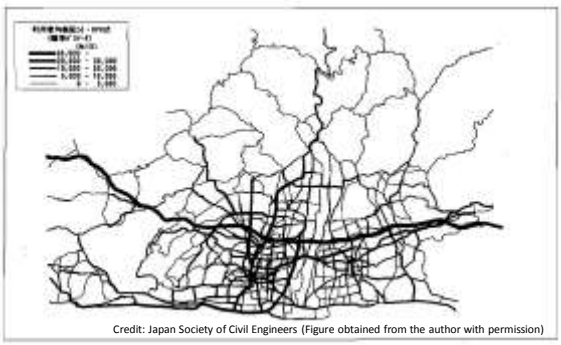
1.8 Traffic game in reality

Traffic around Hamamatsu city, Japan



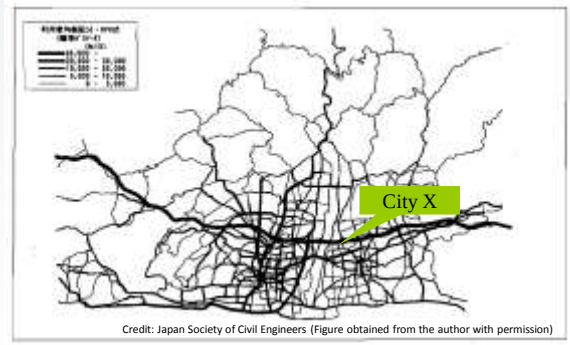
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



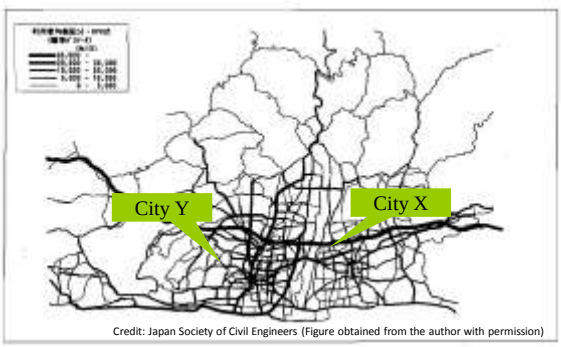
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



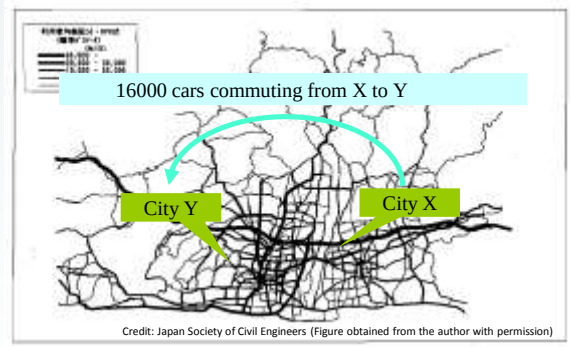
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



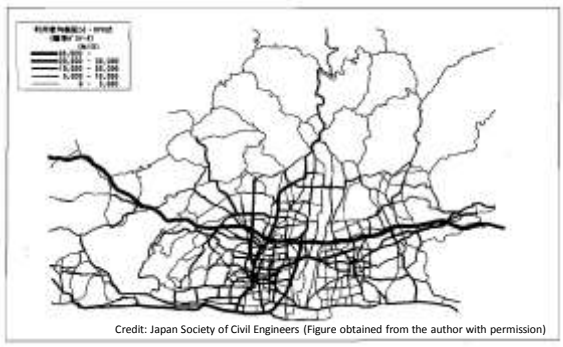
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



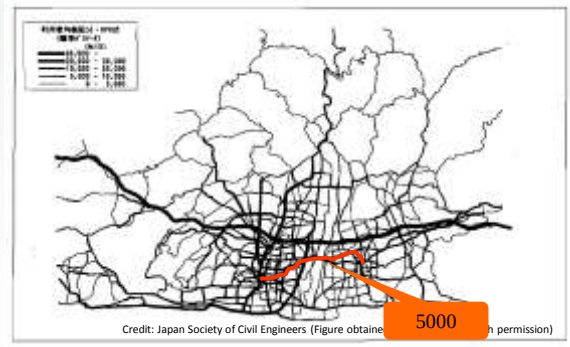
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

First, collect some data



Credit: Japan Society of Civil Engineers (Figure obtaine permission)

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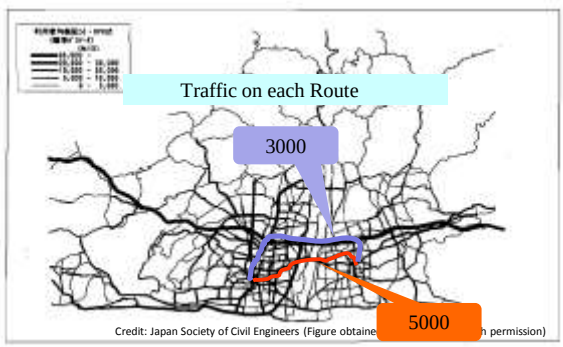

Credit: Japan Society of Civil Engineers (Figure obtaine permission)

Second, compute Nash equilibrium traffic, based on the following information

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- How many cars are commuting from each origin to each destination

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  - ➡ Use the data

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- How many cars are commuting from each origin to each destination
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- The relationship between traveling time and traffic

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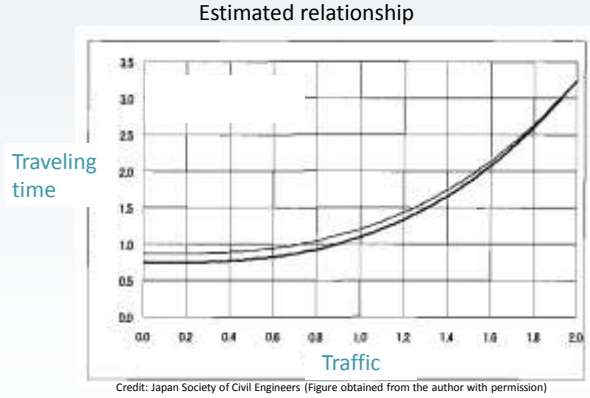
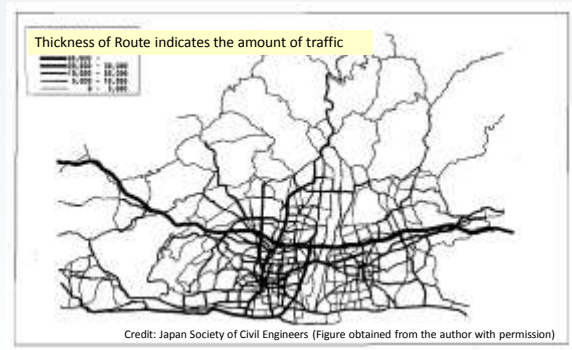
- How many cars are commuting from each origin to each destination
  - ➡ Use the data
- The relationship between traveling time and traffic
  - ➡ Estimate from the data

Estimated relationship

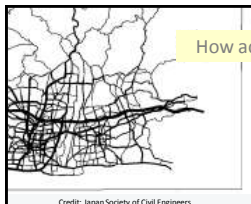


Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

Nash equilibrium traffic

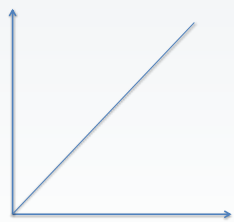


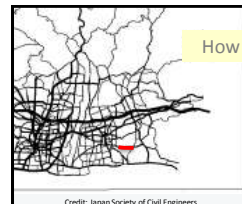
Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)



Credit: Japan Society of Civil Engineers
(Figure obtained from the author with permission)

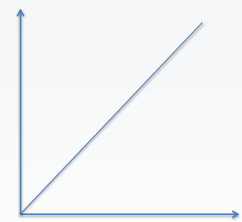
How accurate is Nash equilibrium prediction?



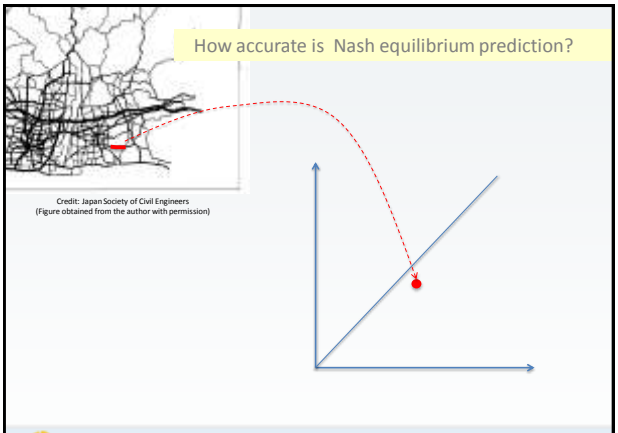


Credit: Japan Society of Civil Engineers
(Figure obtained from the author with permission)

How accurate is Nash equilibrium prediction?



How accurate is Nash equilibrium prediction?



Credit: Japan Society of Civil Engineers
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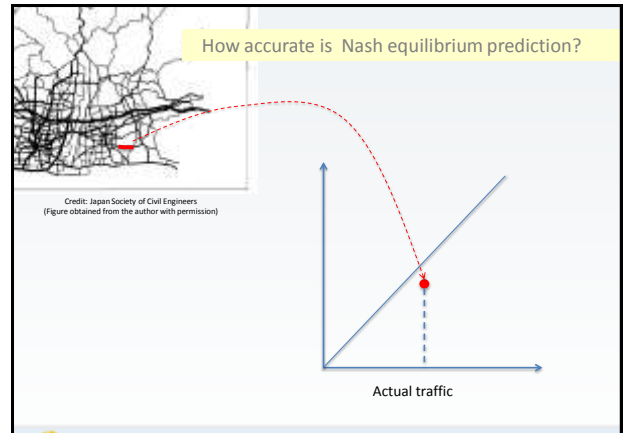
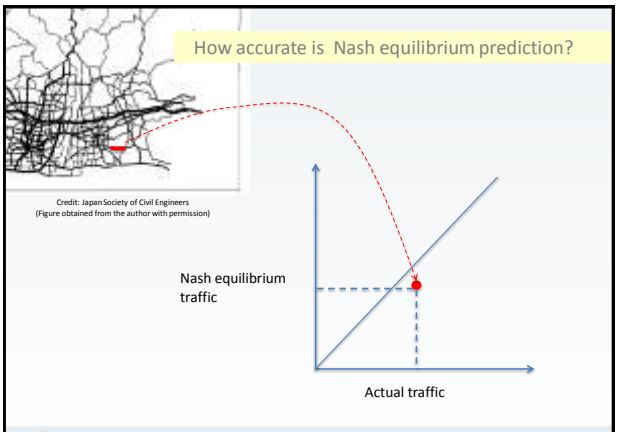
How accurate is Nash equilibrium prediction?



Credit: Japan Society of Civil Engineers
(Figure obtained from the author with permission)

Actual traffic

How accurate is Nash equilibrium prediction?

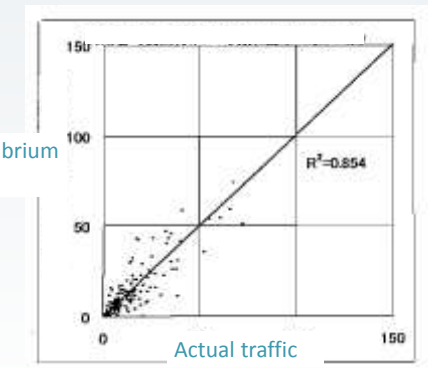


Credit: Japan Society of Civil Engineers
(Figure obtained from the author with permission)

Nash equilibrium traffic

Actual traffic

Nash equilibrium traffic



Credit: Japan Society of Civil Engineers (Figure obtained from the author with permission)

1.9 Location game

- Ice cream vendors A and B on a street

·Ice cream vendors A and B on a street

· Customers are uniformly distributed

·Ice cream vendors A and B on a street

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· Each customer goes to the nearest vendor

·Ice cream vendors A and B on a street

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* A and B at the same location→ they split customers equally

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· A vendors payoff = the number of customers

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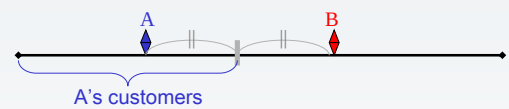

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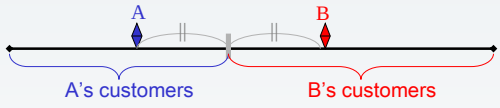

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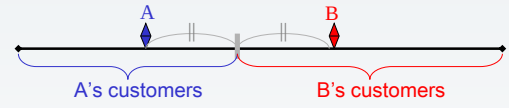

·Ice cream vendors A and B on a street

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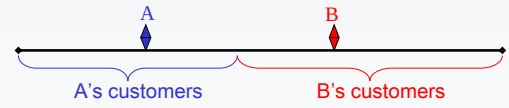
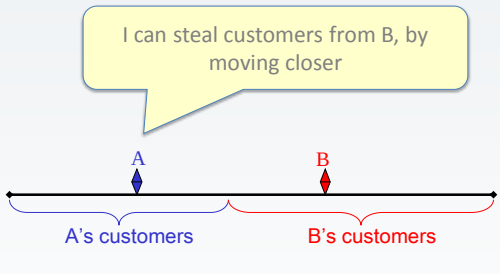
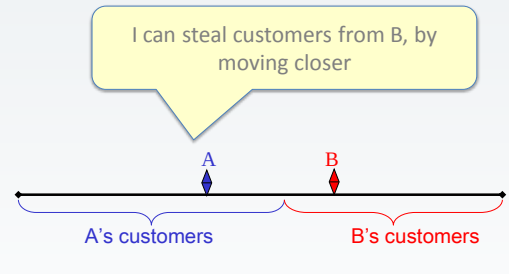
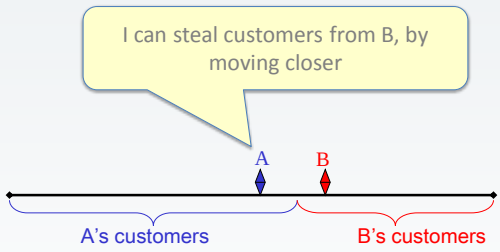
Hotelling's location game

Not a Nash equilibrium

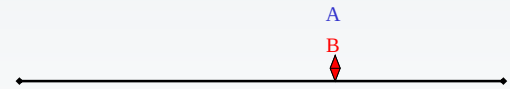






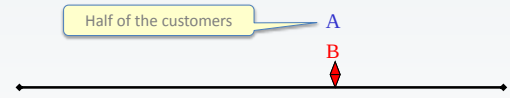


Is this a Nash equilibrium?

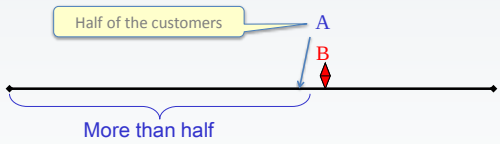


Not a Nash equilibrium

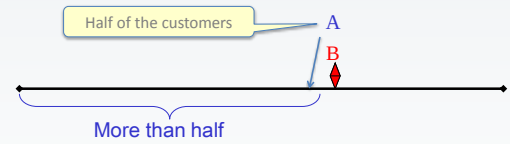
Not a Nash equilibrium



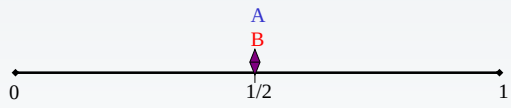
Not a Nash equilibrium



Not a Nash equilibrium



By deviating slightly to the left, A can get more customers

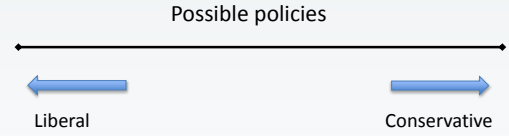


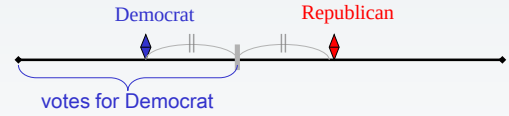
Nash equilibrium

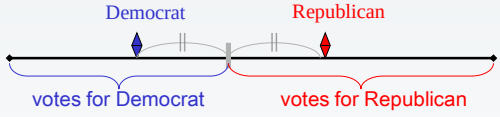
1.10 Policies of two parties

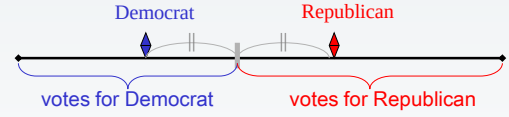
Question 1: What determines the policies of the two parties?

Credit: DonkeyHotey, CC BY



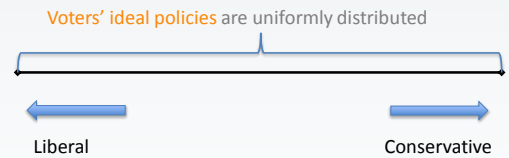


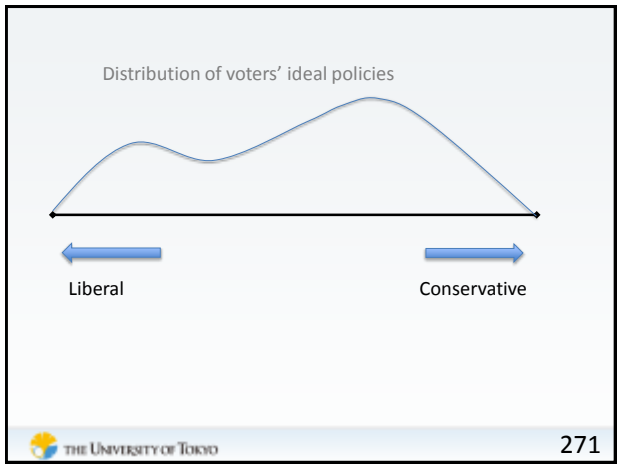


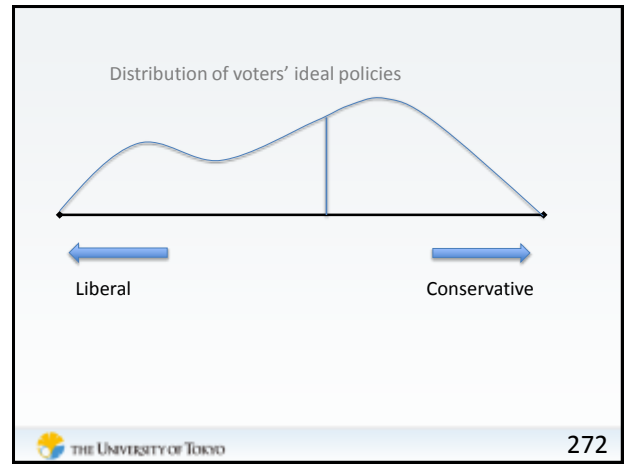


The same as Hotelling's model

Nash equilibrium




Distribution of voters' ideal policies
Liberal
Conservative


Distribution of voters' ideal policies
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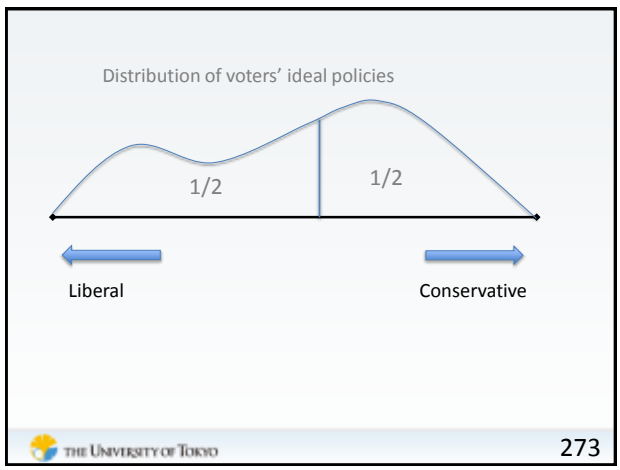
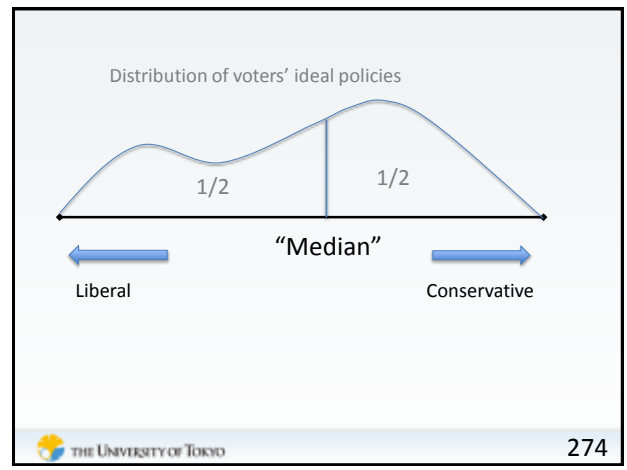
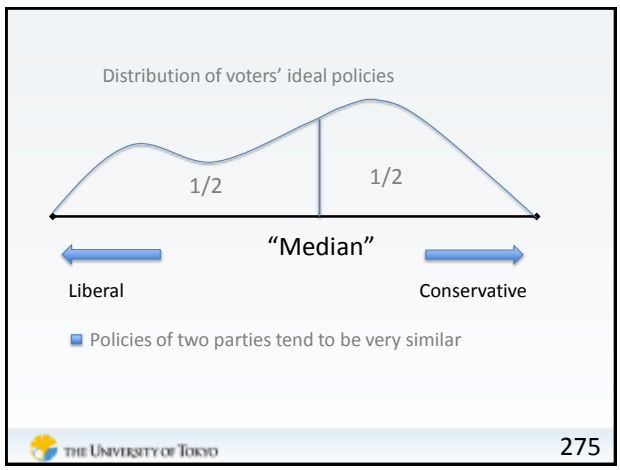
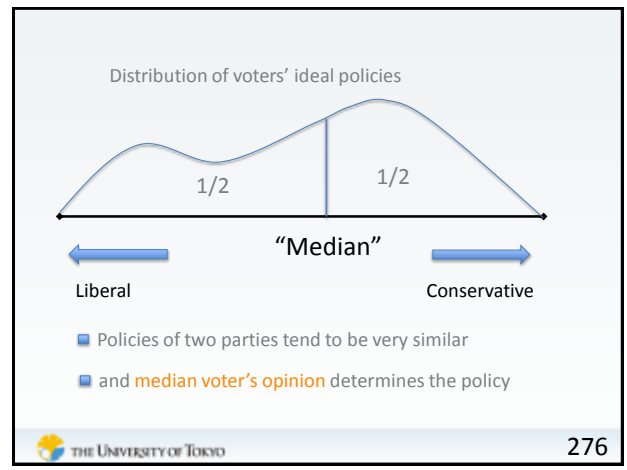
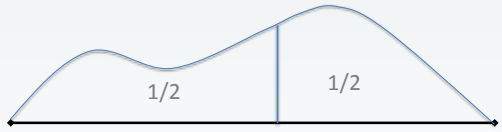

Distribution of voters' ideal policies
1/2
1/2
Liberal
Conservative


Distribution of voters' ideal policies
1/2
1/2
"Median"
Liberal
Conservative


Distribution of voters' ideal policies
1/2
1/2
"Median"
Liberal
Conservative
Policies of two parties tend to be very similar


Distribution of voters' ideal policies
1/2
1/2
"Median"
Liberal
Conservative
Policies of two parties tend to be very similar
and median voter's opinion determines the policy

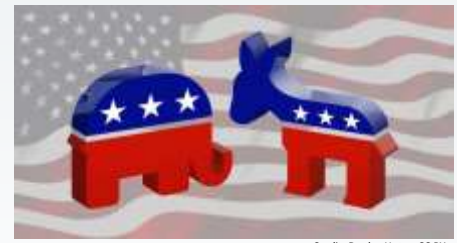
Distribution of voters' ideal policies



- Policies of two parties tend to be very similar
- and median voter's opinion determines the policy

The Median Voter Theorem

What determines the policies of two parties?



Credit: DonkeyHotey, CC BY

What determines the policies of two parties?

Credit: DonkeyHotey, CC BY

Game theoretic prediction is not as accurate as Newton's law

What determines the policies of two parties?

Credit: DonkeyHotey, CC BY

Game theoretic prediction is not as accurate as Newton's law

But it captures an important driving force of players' behavior

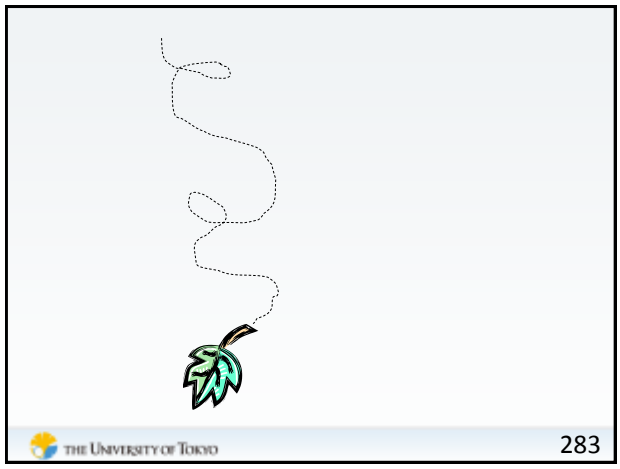
What determines the policies of two parties?

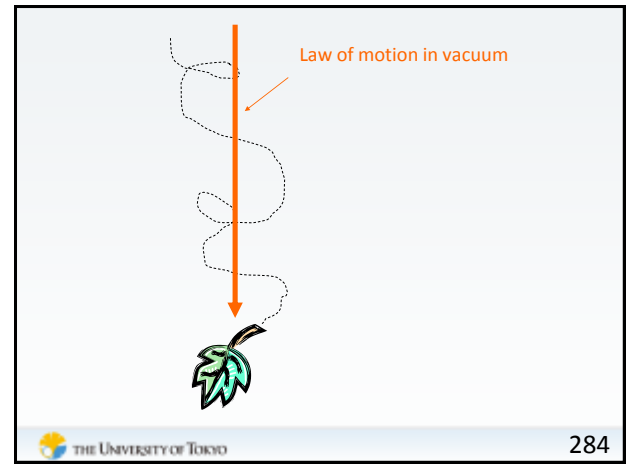
Credit: DonkeyHotey, CC BY

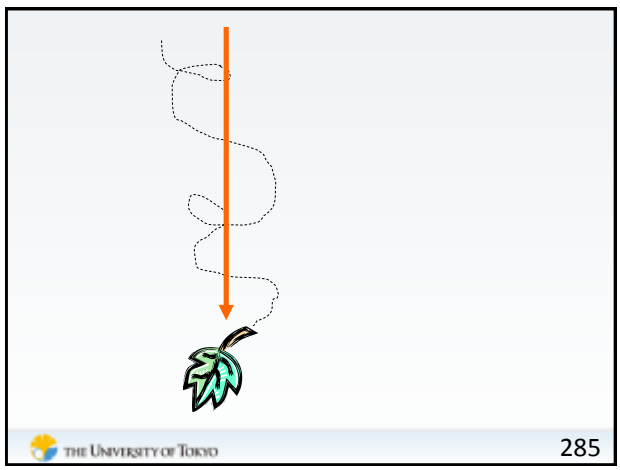
Game theoretic prediction is not as accurate as Newton's law

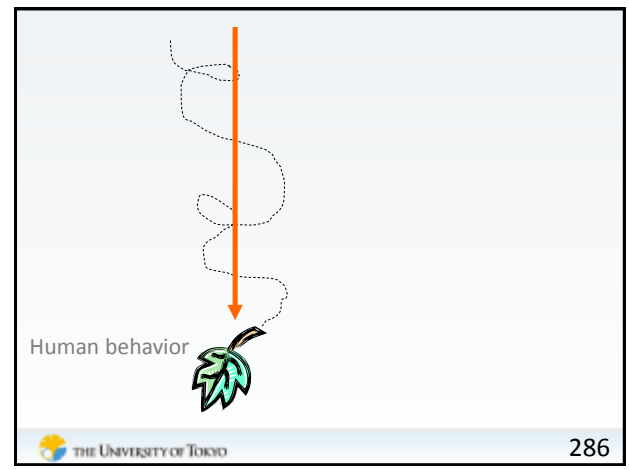
But it captures an important driving force of players' behavior

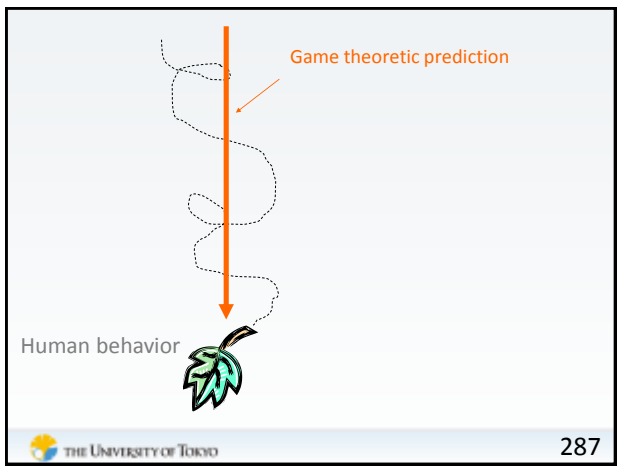
And it provides a useful benchmark of analysis

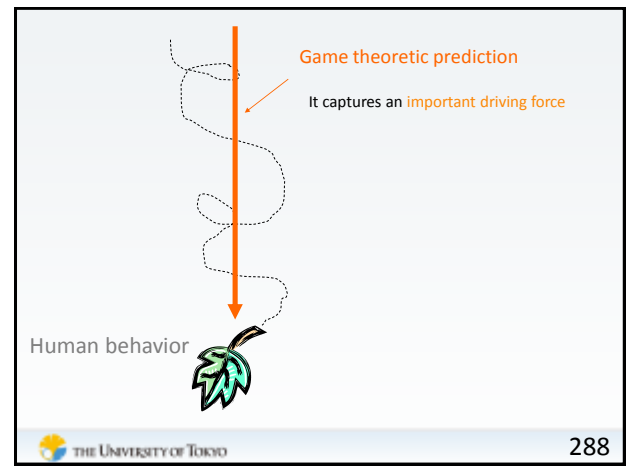


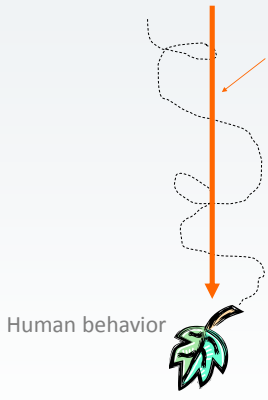

Law of motion in vacuum




Human behavior


Game theoretic prediction
Human behavior


Game theoretic prediction
It captures an important driving force
Human behavior



Game theoretic prediction

It captures an important driving force

It provides a useful benchmark of analysis

Human behavior