CS243: Introduction to Algorithmic Game Theory

Week 10.1 Game Theory in Carsharing (Dengji ZHAO)

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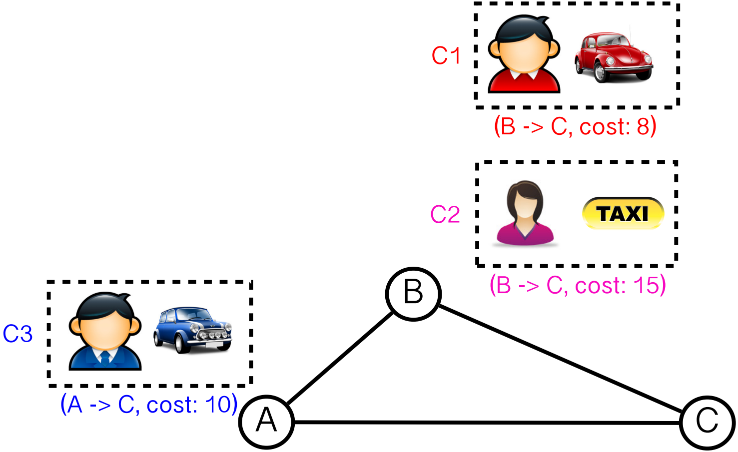
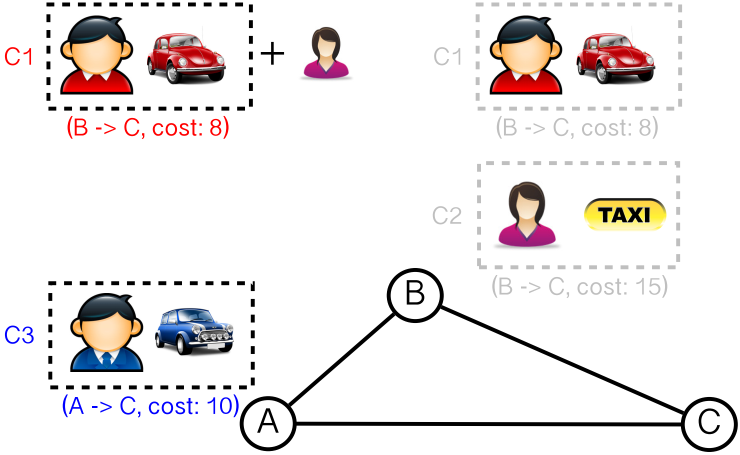
Survey

- Do you think we need a dedicated programming course during your first two-year study, especially before Data Structure course?
  1. If Yes, which language would you prefer: C/C++, Java or Python...? Why?
  2. If no, why?

Ridesharing Example



Ridesharing Example



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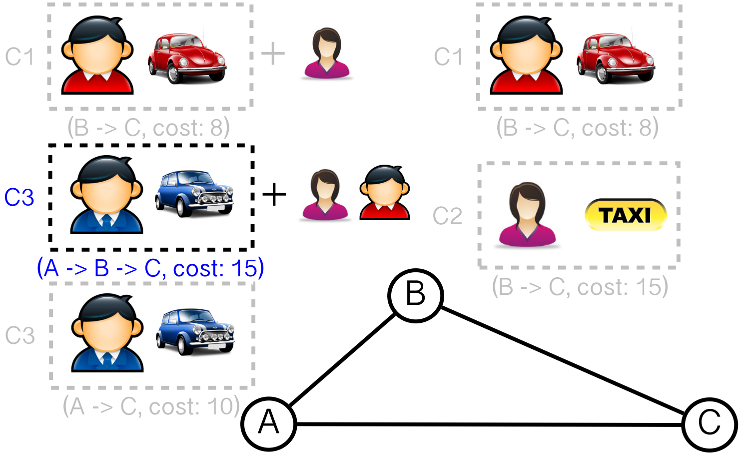

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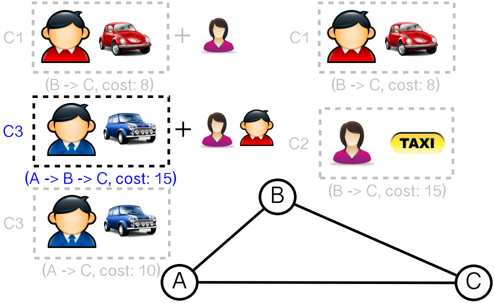


Questions:

- How to arrange the sharing?
- How much should they pay/receive?

History

- Began in the 1940s in North America
- Been promoted because of
  - fuel shortages, air pollution and traffic congestion
- Peaked in the US in 1970 with a commute mode share of 20.4%

Public and Private Promotions

zimride
share the ride

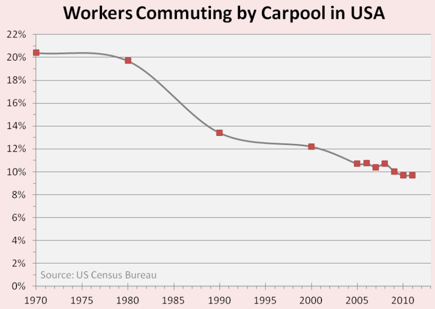
BlaBlaCar

carpooling.com
CLICK. RIDE. SAVE.

UBER vs lyft

People are still NOT well motivated!

not going well...



- Australia (Queensland) will end ridesharing lanes
- The average car carries just 1.6 people

What are the obstacles?

- Safety and Privacy
- Flexibility and Reliability
- ...
- Complicated join procedures
- No free market competition!

What can we do?

Use Mechanism Design to build ridesharing:

- Automated ride matching/scheduling
- Automated (profitable) price setting

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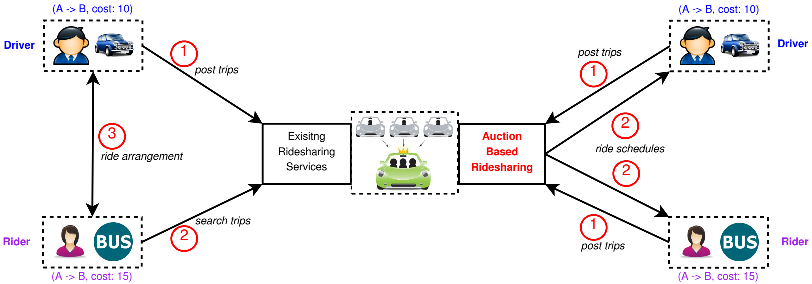

What can we do?

Use Mechanism Design to build ridesharing:

- Automated ride matching/scheduling
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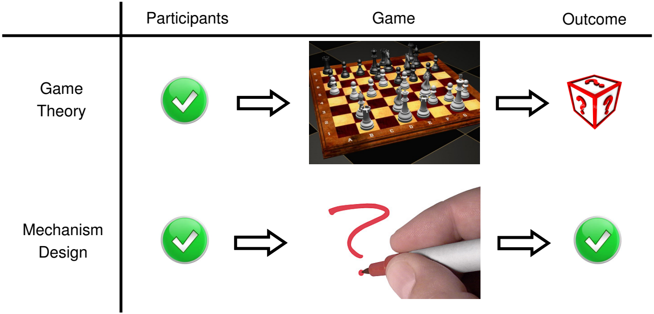
to answer...

Questions:

- How to arrange the sharing?
- How much should commuters pay/receive?

Mechanism Design (Reverse Game Theory)



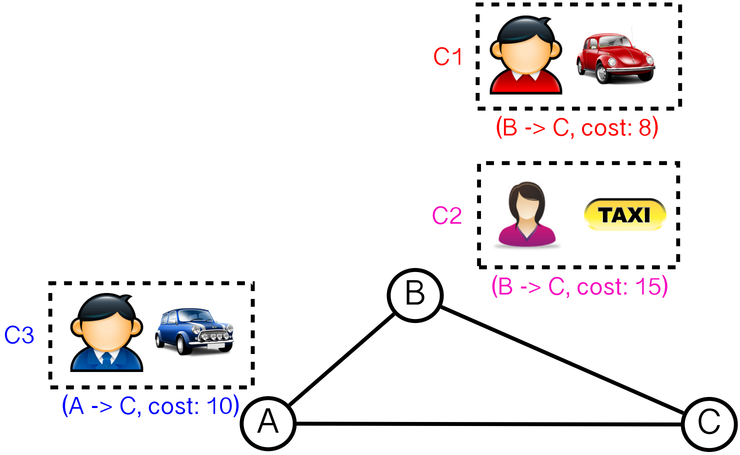
Mechanism design answers...

How to design a mechanism which leads to a desired outcome?

Outline

Outline

System Overview



System Overview

Input:

- Route map: a graph $G = (L, E)$,
  - L: stopping points/locations,
  - E: routes between stopping points,
  - $w(e)$: time required to travel via route $e \in E$.
- Commuter i's private trip/type: $\theta_i = (l_i^d, l_i^a, t_i^d, t_i^a, c_i, q_i)$
  - $l_i^d, l_i^a \in L$: departure and arrival locations,
  - t_i^d, t_i^a: earliest departure and latest arrival time,
  - $c_i \in \mathbb{R}^+$: travel cost to finish the trip,
  - $q_i \in \mathbb{N}$: extra seats available on the trip.

System Overview

Output:

- Allocation/Scheduling:
  - driver: drives and takes riders
  - rider: shares with drivers
  - unmatched: goes with the original travel preference
- Payments:
  - driver: receives money
  - rider: pays money
  - unmatched: no payment

The Goal of the System

Properties of the output:

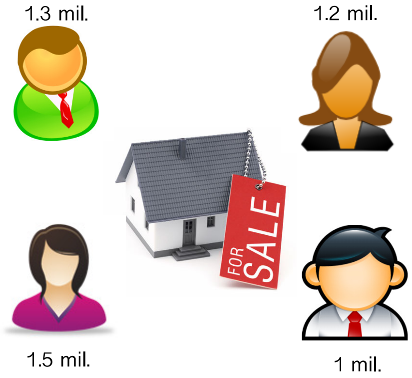
- Minimize the total travel costs (efficiency)
- Incentivize participation and against manipulations
  - commuters never receive negative utility (individual rationality)
  - truthfully reporting their trip information is a dominant strategy (truthfulness)
- Deficit control (budget balance)
  - The system owner should not lose too much money

One Solution: Applying VCG Mechanism

One classical solution: VCG

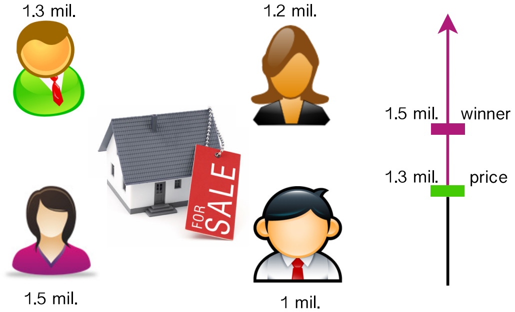
One Solution: Applying VCG Mechanism

Vickrey Auction (*Second Price Auction*)



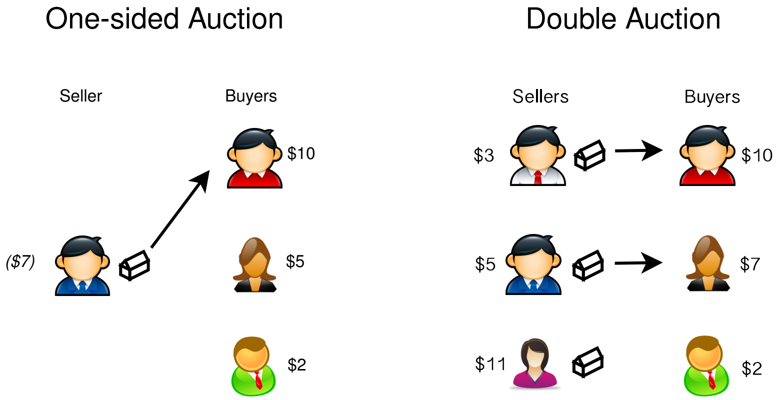
One Solution: Applying VCG Mechanism

Vickrey Auction (*Second Price Auction*)



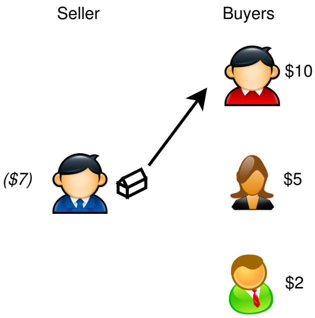
- *Allocation*: the agent with the highest valuation wins
- *Payment*: the harm of others caused by the agent
- Properties: Efficient, Individually Rational, and Truthful.

One Solution: Applying VCG Mechanism

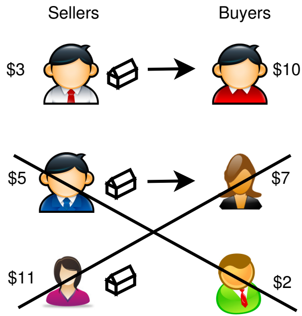


One Solution: Applying VCG Mechanism

One-sided Auction



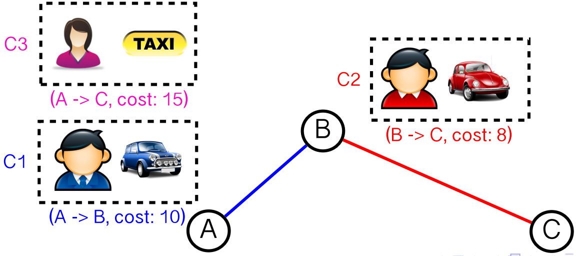
Double Auction



One Solution: Applying VCG Mechanism

Vickrey-Clarke-Groves (VCG) auction

- Efficient (costs minimizing)
- Individually rational (agents never lose money)
- Truthful (truthfully reporting is the best)
- High deficit (Quiz: how much does each driver receive in the following example?)



One Solution: Applying VCG Mechanism

Vickrey-Clarke-Groves (VCG) auction

- Efficient (costs minimizing)
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- High deficit (Quiz: how much does each driver receive in the following example?)

Question

How to control deficit?

Our Solutions (Overview)

We propose...

Fixed-price Mechanisms :

- Flexible deficit control (outperforms VCG)
- Truthful and individually rational
- Very inefficient

VCG with Reserve Prices :

- Flexible deficit control (outperforms VCG)
- Partially truthful and individually rational
- Flexible efficiency control

Balanced Trade Reduction :

- Flexible deficit control (outperforms VCG)
- Truthful and individually rational
- Flexible efficiency control

Outline

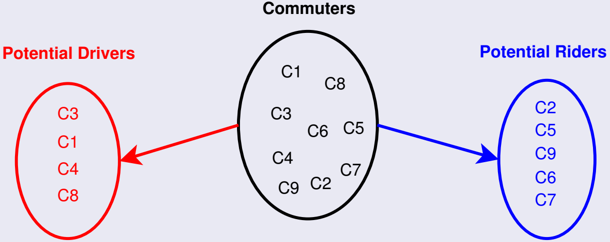
Fixed Payments $x^{fixed}(p^0, p^1)$

Given predefined values $p^0 \geq 0$ (for riders) and $p^1 \leq 0$ (for drivers), fixed payments are defined

- Allocation independent
- Allocation dependent
  - location dependent (e.g. shortest path)
  - detour dependent
  - sharing dependent
  - ...

Dictatorship Mechanism

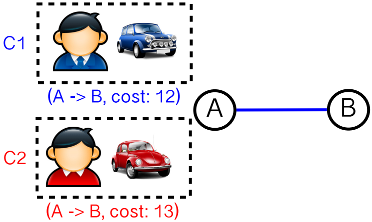
Serial Dictatorship Mechanism with fixed payments



Properties

- truthful and individually rational
- better deficit control than VCG
- very inefficient

Problems of Non-dictatorship Mechanisms



Case I:

- fixedPay = 10
- both prefer driving
- potential problem for deterministic mechanisms

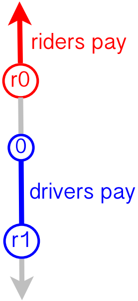
Case II:

- fixedPay = 1
- both prefer riding
- potential problem for all mechanisms

Outline

VCG with Two-Sided Reserve Prices $\mathcal{M}^{VCG}(r^0, r^1)$

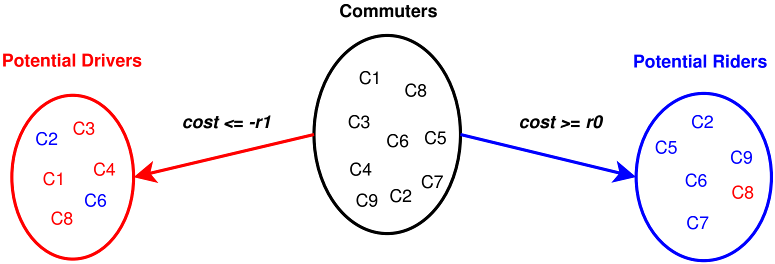
Predefined reserve prices $r^0 \geq 0$ (for riders) and $r^1 \leq 0$ (for drivers),



Note: r_0 and r_1 can be allocation dependent.

VCG with Two-Sided Reserve Prices $\mathcal{M}^{VCG}(r^0, r^1)$

Predefined reserve prices $r^0 \geq 0$ (for riders) and $r^1 \leq 0$ (for drivers),

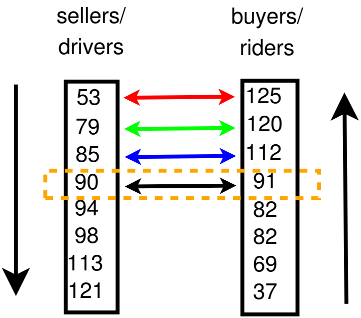


Properties: $\mathcal{M}^{VCG}(r^0, r^1)$ is truthful iff $r^0 \geq -r^1$.

Outline

McAfee's Trade Reduction (1992)

- McAfee's reduction: increase VCG payments via reducing efficiency



VCG payments:

- Riders: 90
- Drivers: -91

Deficit: 4

McAfee's payments:

- Riders: 91
- Drivers: -90

No deficit!

McAfee's Reduction is NOT Truthful in Ridesharing

McAfee's trade reduction is NOT truthful in ridesharing because:

- a commuter who can be allocated as either driver or rider might manipulate/switch!

Balanced Trade Reduction (BTR)

VCG payment for a buyer

$$v_i^b - x_i^{vcg} \geq v_i^s - \hat{x}_i^{vcg}$$

McAfee's payment for a buyer

$$v_i^b - (x_i^{vcg} + \delta_1) \ngeq v_i^s - (\hat{x}_i^{vcg} + \delta_2)$$

Balanced Trade Reduction payment for a buyer

$$v_i^b - (x_i^{vcg} + \delta) \geq v_i^s - (\hat{x}_i^{vcg} + \delta)$$

Balanced Trade Reduction (BTR)

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Balanced Trade Reduction payment for a buyer

$$v_i^b - (x_i^{vcg} + \delta) \geq v_i^s - (\hat{x}_i^{vcg} + \delta)$$

Properties of BTR:

- Truthful, Individually Rational, almost Efficient, but has Deficit.

What is NEW?

- The first comprehensive ridesharing model studied from a pure game-theoretic point of view.
- Auction-based ridesharing system incentivizing participation.
- Flexible deficit control rather than completely remove deficit (investment opportunity).

Future Work

- The problem of finding optimal schedules is computationally hard (optimal in range).
- Allow agents to submit trips dynamically over time (online mechanism design).
- Collaboration with existing public/private transports (Uber are banned in many countries!).
- Trips with uncertain commitment.

References

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- Dengji Zhao, Dongmo Zhang, Enrico Gerding, Yuko Sakurai, Makoto Yokoo: **Incentives in Ridesharing with Deficit Control.** In the Proceedings of the 13th International Conference on Autonomous Agents and Multiagent Systems (AAMAS-14)
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