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Designing cooperative interaction of automated vehicles with other road users in mixed traffic environments

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Empirical game theory of pedestrian interaction for autonomous vehicles

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Outline

I. Motivations & Introduction
II. Game Theory Model
III. Results
IV. Conclusion & Future work

Motivations

A “Barnes dance” or “scramble” crossing between Hollywood and Highland, Los Angeles. Real-world pedestrian-pedestrian interactions

Motivations: EU H2020 InterACT project

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Partners

DLR · BMW · CRF · BOSCH · HELLA · ICCS · Technical University of Munich · University of Leeds

Introduction

Trials of an autonomous vehicle : La Rochelle (France) and Trikala (Greece)

citymobil2.eu

Conclusion (Madigan et al.): **pedestrians intentionally obstruct the way of the autonomous vehicle once every 3 hours**

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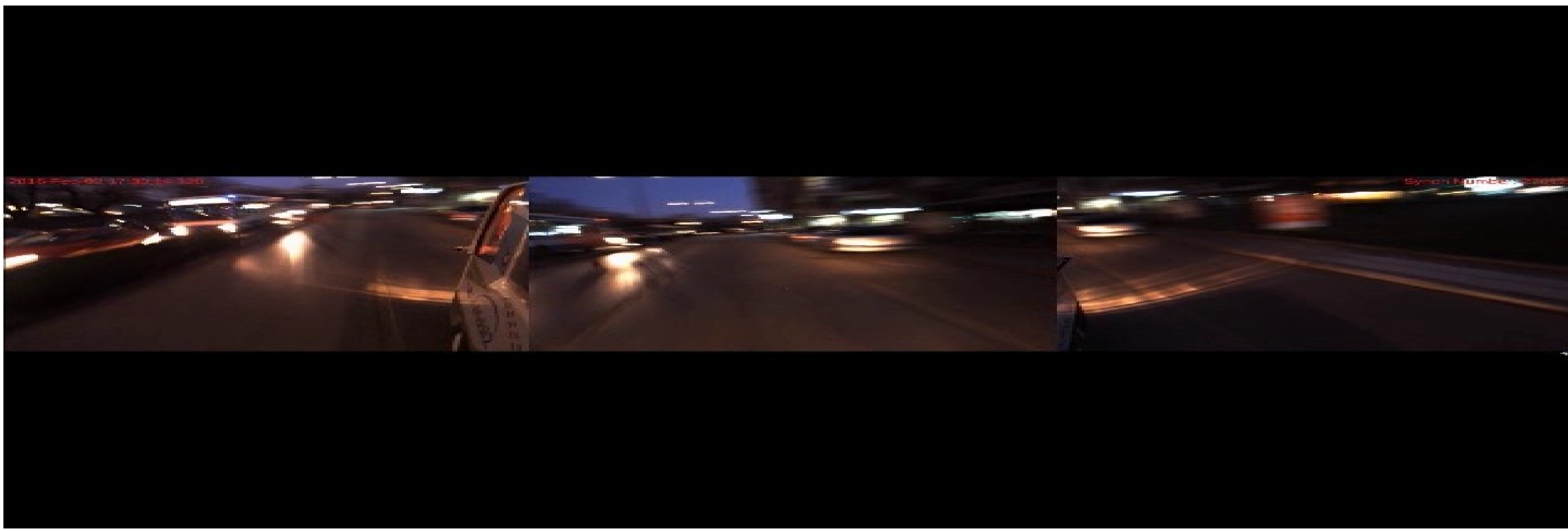
The Big Problem With Self-Driving Cars Is People

Rodney Brooks, *Rethink Robotics*



Video: CityMobil2

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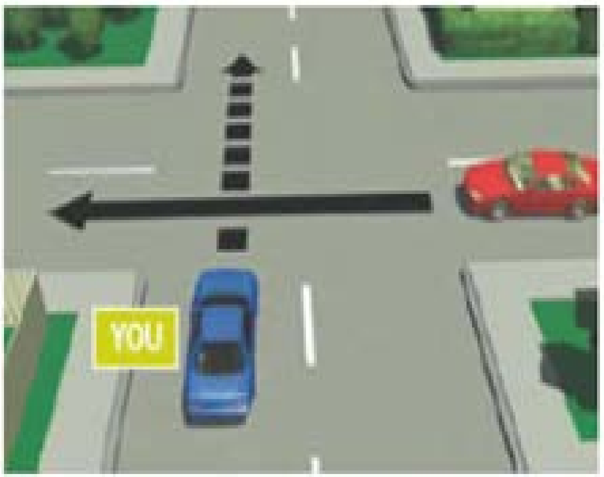
Game theoretic approach: chicken game



Scenario of the chicken game

- **2 vehicles negotiating for priority at an unmarked intersection**

2 possible actions :

- Drive straight => winner
- Swerve away => loser

But if a collision occurs => both bigger losers

$Y \setminus X$	$a_X = swerve$	$a_X = straight$
$a_Y = swerve$	(0,0)	(-1, +1)
$a_Y = straight$	(+1, -1)	(-100,-100)

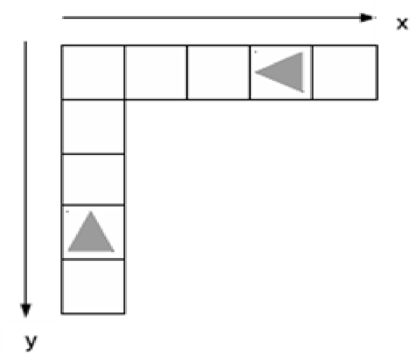
Payoff matrix

Why game theory ?

Framework to model conflict and cooperation between rational decision-makers

Method : Sequential Chicken Model

Assumption: Both players make their action selection simultaneously



Scenario of chicken game

Sequential chicken game = a sequence of one-shot games

⇩

Payoffs of sub-games at state $(y > 1, x > 1, t)$ becomes recursive of function of the next steps $(y - a_Y, x - a_X, t + 1)$ where $a_Y, a_X \in \{1, 2\}$

Discrete space, time and speed

Symmetric Utilities

- Collision utility: e.g. -100
- Time delay utility: e.g. 1

Considering the value $v_{y,x,t} = (v^Y_{y,x,t}, v^X_{y,x,t})$ at state (y, x, t) the sub-game's payoff is then given by:

$$v_{y,x,t} = v\left(\begin{bmatrix} v(y-1, x-1, t+1) & v(y-1, x-2, t+1) \\ v(y-2, x-1, t+1) & v(y-2, x-2, t+1) \end{bmatrix}\right)$$

(Nash) *Equilibrium*

- Fundamental concept of game theory by John Nash in 1950
- ***Equilibrium***: pair of strategies for the two players such that if either player knew the other's they wouldn't change their own
- What if there are **multiple *equilibria*** such as in the chicken game ?

$Y \setminus X$	a_X=swerve	a_X =straight
a_Y=swerve	(0,0)	(-1, +1)
a_Y =straight	(+1, -1)	(-100,-100)

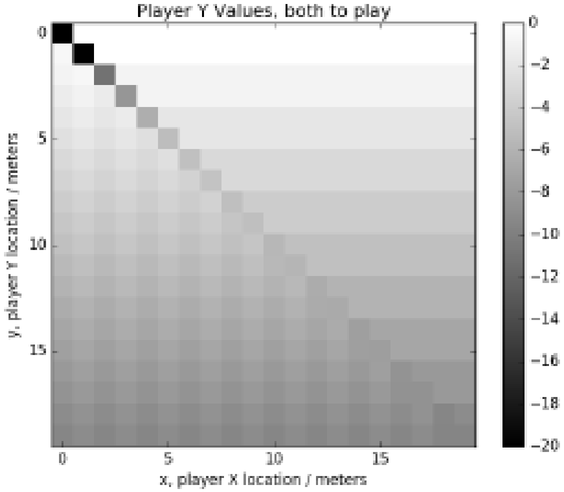
Payoff matrix

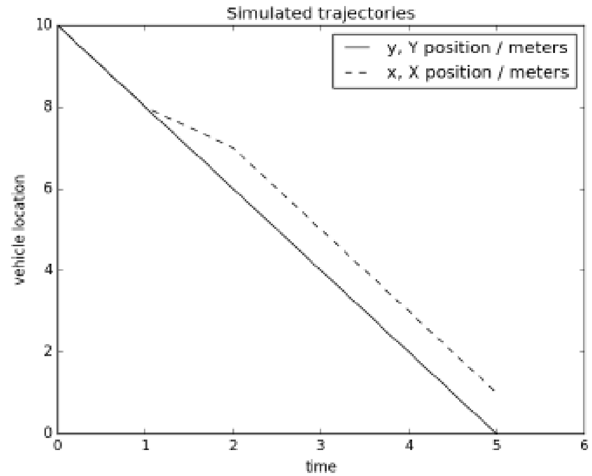
- ➢ Discard dominated equilibria
- ➢ Discard non-Evolutionary Stable Strategy (ESS) equilibria

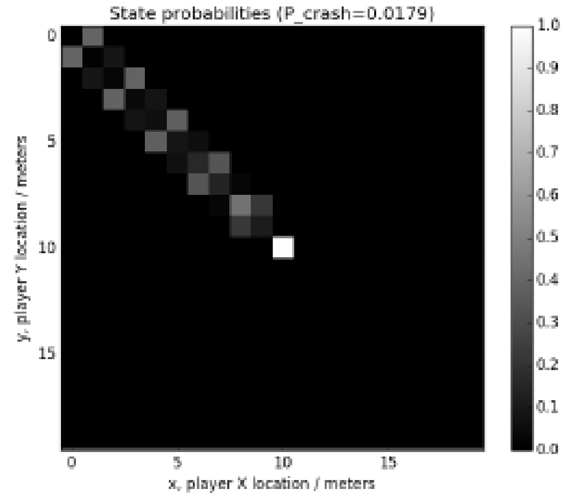
and

- ➢ General rule: set a certain probability to each equilibrium => a *mixed* strategy

Results of the Sequential Chicken Model







Collision Probability:

- 1.79 % for collision utility -20
- 0.7% for collision utility -100

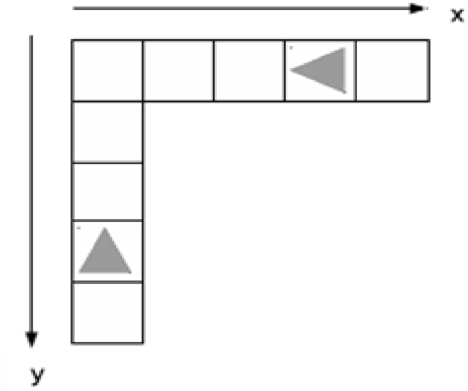
Figures from Fox et al. (VEHITS, 2018)

Experiments

16 participants (22 to 48 years old) divided in 8 groups of 2 played:

- Natural game: 3 times
- Chocolate games: 3 times with chocolate rewards

$$P(D \mid \theta, M') = \prod_{game}\prod_{turn}\left[(1-s)\,\mathrm{P}\left(d_Y^{game,turn} \mid y, x, \theta, M\right)\mathrm{P}\left(d_X^{game,turn} \mid y, x, \theta, M\right) + s\left(\frac{1}{2}\right)\right].$$

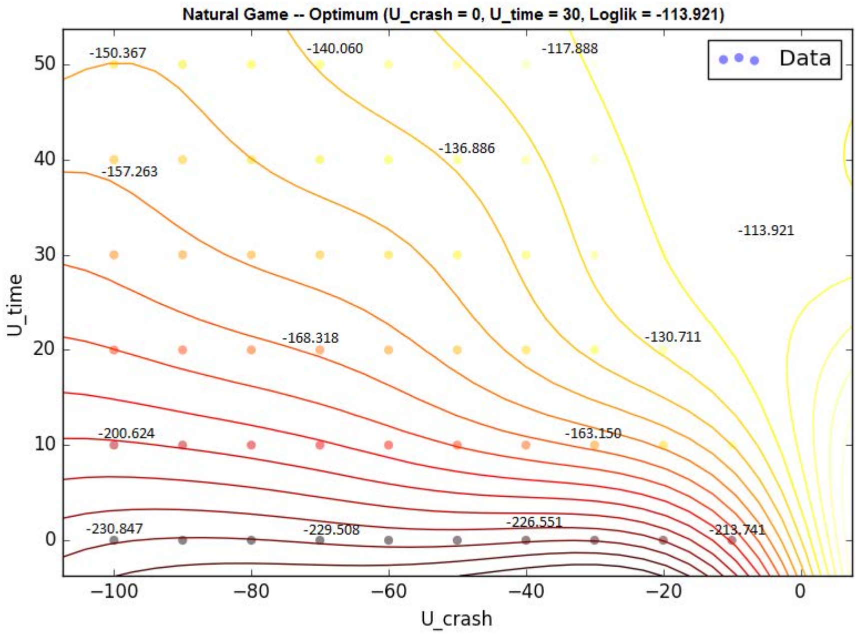


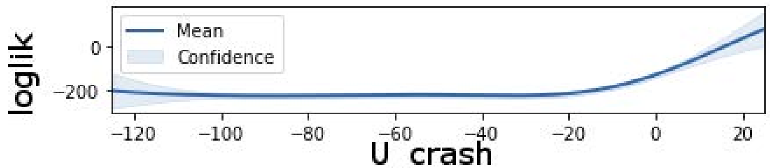
Scenario of chicken game

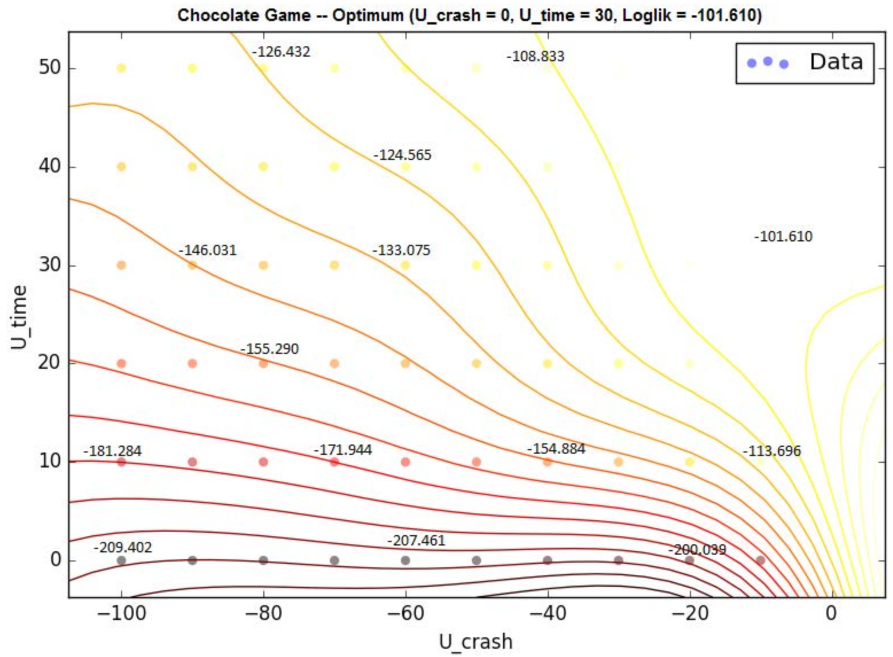
Results

Type of Game	Number of Games	Collisions	Average Delay (box)	Average Time Delay (s)
Natural	24	5	$\frac{26}{19} \approx 1.368$	$\frac{26}{19*2} \approx 0.684$
Chocolate	24	8	$\frac{18}{16} = 1.125$	$\frac{18}{16*2} = 0.5625$
Total	48	13	$\frac{44}{35} \approx 1.257$	$\frac{44}{35*2} \approx 0.628$

Gaussian Process Regression







Conclusion

- Sequential Chicken game theory model, for interaction between an AV and other road user
- (e.g pedestrian)
- Small probability for a collision to occur as a threat
- Owning a big car is a rational decision (other cars get out of the away)
- Experiment with human participants: preference for saving time than avoiding collision

Future work

- Continuous version of the model
- Giving and reading utility signals between the agents
- Fit parameters to human-human interactions using other techniques, video – tracking data etc.
- Use of new (visual or audio) signaling conventions

Thank you for your attention !

Any questions ?

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