Games with misinformed views

17th Symposium and Summer School On Service-Oriented Computing

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Introduction

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- Multi-agent system: a group of autonomous intelligent and individual participants
- Usually, they try to achieve a goal, solve a problem, etc.
- Centralized/Decentralized techniques

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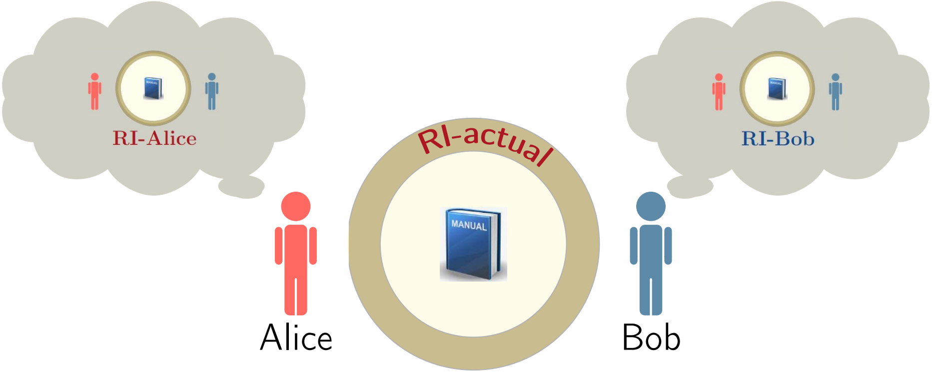
} Game theory

Cases of subjective views

- Malicious intervention (e.g., fake news, deception, fraud)
- Wrong beliefs (e.g., cognitive limitations)
- Environmental changes (e.g., when the game changes due to external factors, without players' knowledge)
- Random or undeliberate mistakes (e.g., disconnections, communication jams, noise)
- Individual attitude (e.g. altruism, spite)

Subjective views



Cases of study

Agents have

- different attitudes towards the interaction
- erroneous information about the interaction

Cases of study

Agents have

- different attitudes towards the interaction $\rightsquigarrow$ Perception parametrized models
- erroneous information about the interaction $\rightsquigarrow$ Misinformation games

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> - How do we model the concept of subjective views?
> - How decisive are the subjective views in terms of system's efficiency?
> - How do we study the above in different classes of games?

Illustrative example I

- Interactions
- Agents
- Choices
- Gains

ERCIM CWI

Illustrative example I

- Games (G)
- Agents (N)
- Strategies (S)
- Payoffs, utilities (P)

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Table: Game G.

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! Solution concept, Nash equilibrium (NE, [S. Nash, '51]), no agent has incentives to alter her choice

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! Solution concept, Nash equilibrium $(\mathcal{NE}$, [S. Nash, '51]), no agent has incentives to alter her choice

! Measure the performance of the system (e.g. use social welfare SW)

Perception parametrized models

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- The outcome of the interaction is influenced by the attitudes of the agents

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- Agents interpretation is too restrictive
- Solution concepts are questionable
- Inefficiency in the performance of a system

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- Agents interpretation is too restrictive $\rightsquigarrow$ utilities
- Solution concepts are questionable $\rightsquigarrow$ NE
- Inefficiency in the performance of a system $\rightsquigarrow$ PoA

Setting

- A set of resources and a set of agents
- Each resource has a cost function
- Each agent chooses a subset of resources, and experiences a cost
- Each agent has a perceived cost over the resources $\leftsquigarrow$ subjective views

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- Each agent has a perceived cost over the resources $\rightsquigarrow$ generalized congestion games
- General class of games in AGT

Setting

Specifications

- A set of resources (m) and a set of agents (n)
- Each resource (e) has a cost function
- Each agent chooses a subset of resources, and experiences a cost ($c_e(x_e)$, cost only depends on load x_e on e)
- Each agent has a perceived cost over the resources ($\tilde{c}_e(x_e)$)

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- Optimize social welfare (SW, sum of the individual gains)

Some literature

altruism in atomic congestion games [Caragiannis et al, TALG '10]

altruism in social contribution games [Rahn-Schäfer, WINE '13]

complex underlying social structure and player-specific behavior [Anagnostopoulos et al, TCS '15]

biased perceived utilities [Meir-Parkes, SIGMETRICS '15]

partially altruistic agents congestion games [Chen et al, TEAC '17]

plugged in perceived social cost [Kleer-Schäfer, TCS '19]

generalized weighted congestion games [Biló, TCS '22]

Unifying approach

Given a game $G = (N, \{S_i\}_{i \in N}, \{C_i\}_{i \in N})$ we have

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I. altruism level $\alpha_i \in [0, 1]$, α−altruistic game

- $G^\alpha = (N, \{S_i\}_{i \in N}, \{C_i^\alpha\}_{i \in N})$, with $C_i^\alpha(x) = (1 - \alpha_i) C_i(x) + \alpha_i C(x)$

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II. perception parameters $\rho \geqslant 0$ and $\sigma \geqslant 0$, PP$-$congestion game

- $G^{\rho,\sigma} = (N, \{S_i\}_{i \in N}, \{C_i^\rho\}_{i \in N})$, with $C_i^\rho(x) = \sum_{e \in s_i} c_e(1 + \rho(x_e - 1))$
- social cost, $C^\star(x) = \sum_{i \in N} C_i^\star(s)$

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Interchange between the G and *perceived* games $G^\star$

Price of Anarchy

Definition: Price of Anarchy [KP, STACS '99]

A metric that measures the effect of selfishness on social welfare, compared to the optimum of the actual game,

$$\mathrm{PoA} = \frac{f(\mathrm{opt})}{\min_{\sigma \in \mathrm{NE}} f(\sigma)}$$

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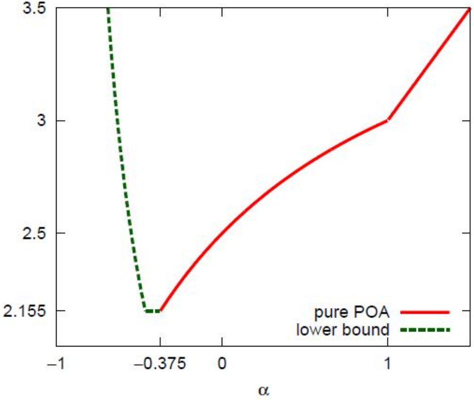
- Study the efficiency of equilibria in interactions
- Can different attitudes be beneficial for the system?

Price of Anarchy

α-altruistic games



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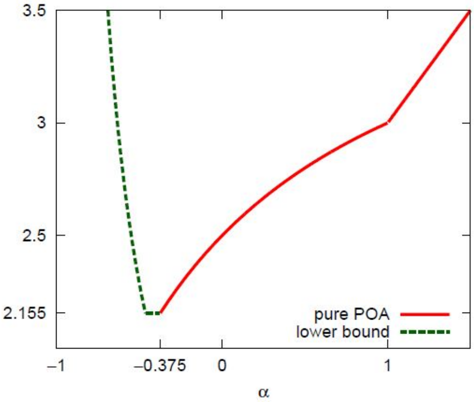

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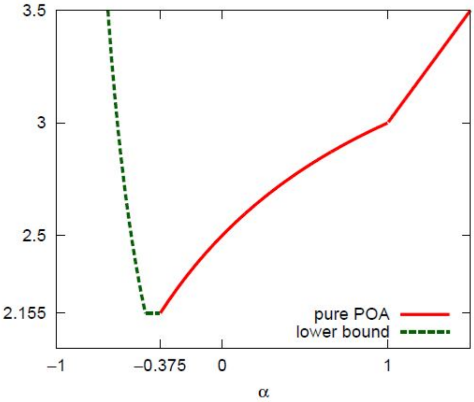

- Altruistic behavior might be harmful!
- Spite might be beneficial?

PP-congestion games

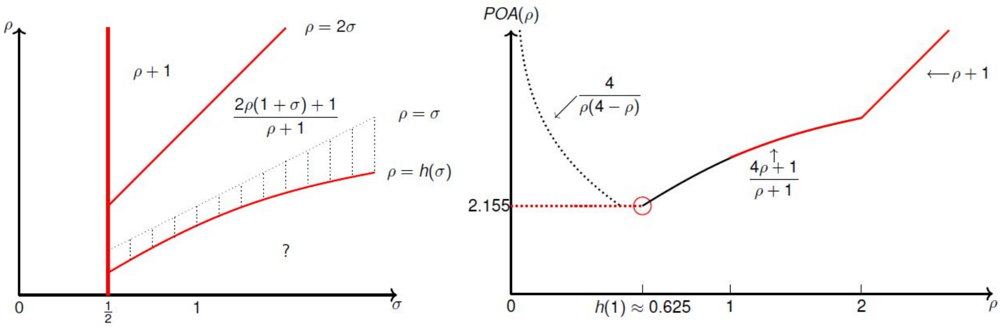

Figure: $\mathrm{PoA}(\sigma, \rho)$ for affine cost functions. (left) $\sigma \in \mathbb{R}_{\geqslant 0}$, (right) $\sigma = 1$, see [P. Kleer and G. Schäfer, *Tight inefficiency bounds for perception-parameterized affine cost functions*, TCS '19]

Summary

- Unifying approach for complex games
- Exploit the relation between game G and perceived games $G^\star$
- Study the inefficiency of the interaction
- Tackle inefficiency using perceived games $G^\star$

Misinformation games

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Motivation

- Enhance agents interpretation
- Solution concepts are questionable
- Inefficiency in the performance of a system

Illustrative Example II

Two criminals, X and Y, are arrested and imprisoned in solitary confinement with no means of communicating with the other. The prosecutors have enough to convict both only on a lesser charge. Simultaneously, the prosecutors offer each prisoner a bargain. Each prisoner can either betray the other, or remain silent.
The possible outcomes are:

- C_1 If X and Y each betray the other, each of them serves two years in prison.
- C_2 If X betrays Y but Y remains silent, X will take a minor penalty and Y will serve three years in prison.
- C_3 If X remains silent but Y betrays X, X will serve three years in prison and Y will take a minor penalty.
- C_4 If X and Y both remain silent, both of them will serve only one year in prison (on the lesser charge).

Consider the interaction where two agents X, Y have two choices A and B. This interaction is presented through the following table,

	S	B
S	$(-1,-1)$	$(-3,0)$
B	$(0,-3)$	$(-2,-2)$

Now consider that, in reality, prosecutors do not have any evidence about X and Y. So X, Y must be compensated, thus in reality it holds

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Now this misinformation twist leads both agents to know the following tables,

	S	B
S	$(-1,-1)$	$(-3,0)$
B	$(0,-3)$	$(-2,-2)$

(a) X's view.

	S	B
S	$(-1,-1)$	$(-3,0)$
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(b) Y's view.

	S	B
S	$(1,1)$	$(-3,0)$
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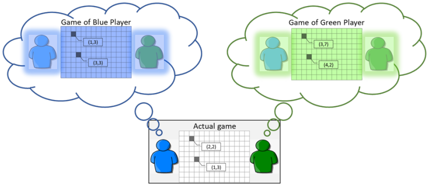
(c) actual.

It holds,

- Agents know the specification of the opponents (**complete**).
- Agents know wrong game specifications (**incorrect**).



Some literature

Hypergames

[Bennett, Sasaki, Kovach et al.] etc.

Games with Unawareness

[Copic and Galeotti, Halpern and Rêgo, Schipper] etc.

misspecified models

[Esponda and Pouzo]

Problem Specifications

1. Agents are rational, intelligent, self-interested and of equal "capabilities"
2. Normal-form games
3. Agents' view of interaction
4. Abstract specifications for misinformation

   One-shot (static) interactions

Problem Specifications

1. Agents are rational, intelligent, self-interested and of equal "capabilities"
2. Normal-form games
3. Agents' view of interaction
4. Abstract specifications for misinformation
5. Iterative interactions

Framework

Definition: Misinformation games [Varsos et al, PRICAI '19]

A *misinformation game* is a tuple $mG = \langle G^0, G^1, \ldots, G^{|N|} \rangle$, where all G^i are normal-form games and G^0 contains $|N|$ players

- G^0 is called the *actual game*
- G^i represents the game that player i thinks that is being played, $i \in [|N|]$
- Special class *canonical misinformation games*
  - For any i, G^0, G^i differ only in their payoffs
  - In any G^i, all players have an equal number of pure strategies
- Equilibrium concept, **natural misinformed equilibrium** (nme), where no player has incentives to deviate in her view

Illustrative example II

Consider the $\mathfrak{m}G = \langle G^0, G^r, G^c \rangle$, with payoff matrices.

	S	B
S	(3, 2)	(1, 1)
B	(1, 1)	(2, 3)

(a) G^0, G^c payoff matrices.

	S	B
S	(2, 2)	(0, 3)
B	(3, 0)	(1, 1)

(b) G^r payoff matrix.

NE G^c (G^0): $\{((1,0),(1,0)),\ ((0,1),(0,1)),\ ((2/3,1/3),\ (1/3,2/3))\}$

NE $G^r : \{((0,1),(0,1))\}$

$\mathfrak{nme}$ $\{(0,1)\} \times \{(1,0),\ (0,1),\ (1/3,2/3)\}$

Results

Lemma

We can transform any non-canonical $\mathfrak{mG}$ into a canonical $\mathfrak{mG}$ without affecting its strategic behaviour.

Proposition: Existence

Any canonical $\mathfrak{mG}$ has at least one $\mathfrak{nme}$.

Proposition: Complexity

The computation of a $\mathfrak{nme}$ of a $\mathfrak{mG}$ is **PPAD**-complete.

Price of Misinformation

Definition: Price of Misinformation [Varsos et al, PRICAI'19]

A metric that measures the effect of misinformation on social welfare, compared to the optimum of the actual game,

$$\mathrm{PoM} = \frac{f(\mathrm{opt})}{\min_{\sigma \in nme} f(\sigma)}$$

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$$\mathrm{PoM} = \frac{f(opt)}{\min_{\sigma \in nme} f(\sigma)}$$

- $\frac{\mathrm{PoM}}{\mathrm{PoA}} = \frac{\min_{\sigma \in NE} f(\sigma)}{\min_{\sigma \in nme} f(\sigma)}$.

e.g. PoA: $15/10 = 3/2$, PoM: $15/12 = 5/4$ and $\mathrm{PoM} < \mathrm{PoA}$

Adaptation procedure

Adaptation Procedure

- Iterative interaction
- Agents *adapt* and *reconsider* their views

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Consider a game played in *multiple turns*:

- We start from a *root* $\mathfrak{m}\mathrm{G}$
- In each turn the agents pick a *nme*
- The agents rewards derived from the G^0
- After receiving their payments, the agents *update* G^{i}s
- We call this process **Adaptation procedure**

Update

Position Vectors:

- Consider a $\mathfrak{nme}$ σ
- $\chi(\sigma)$ denotes the positions of the strategies, played with *positive probability*
- We call $\vec{v} \in \chi(\sigma)$ *position vectors*

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Update Operation:

1. Let a position vector $\vec{v}$
2. Let $u = P^0(\vec{v})$ be the *objective* payment of the players
3. We *update* the *subjective* payoff matrices of the players P^i, i.e. $P^i(\vec{v}) \leftarrow u$
4. We denote the *resulting* misinformation game with $mG_{\vec{v}}$

Running example

	s_1	s_2
s_1	$(4, 9)$	$(3, 1)$
s_2	$(4, 5)$	$(1, 0)$

(a) X's view.

	s_1	s_2
s_1	$(3, 6)$	$(0, 6)$
s_2	$(3, 4)$	$(5, 3)$

(b) Y's view.

	s_1	s_2
s_1	$(5, 1)$	$(3, 1)$
s_2	$(5, 4)$	$(1, 7)$

(c) actual.

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G^X $\quad \mathrm{NE} = \{((1,0),(1,0)),((0,1),(0,1))\}$

G^Y $\quad \mathrm{NE} = \{((1/3,2/3),(2/3,1/3))\}$

nme $\quad \mathrm{NME}(mG) = \{((1,0),(2/3,1/3)),((1,0),(2/3,1/3))\}$

$$\chi(\mathrm{NME}(mG)) = \{(1,1),(1,2),(2,1),(2,2)\}$$

Running example

Update at $\vec{v} = (1, 1)$

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Adaptation procedure

Definition: Adaptation procedure [Papamichail et al, SETN '22]

For a set M of misinformation games, we set:

$$\mathcal{AD}(M) = \{mG_{\vec{u}} \mid mG \in M, \vec{u} \in \chi(\sigma), \sigma \in NME(mG)\}$$

We define as Adaptation procedure of a set of misinformation games M to be the iterative process such that:

$$\begin{cases} \mathcal{A}D^{(0)}(M) = M \\ \mathcal{A}D^{(t+1)}(M) = \mathcal{A}D^{(t)}(\mathcal{A}D(M)) \end{cases}$$

for $t \in \mathbb{N}_0$.

Adaptation procedure

- **End Criterion**, $\mathcal{AD}^{\ell+1}(\mathfrak{M}) = \mathcal{AD}^{\ell}(\mathfrak{M})$, for some $\ell < \infty$

Theorem

For ever finite $\mathfrak{mG}$, the procedure terminates after a finite number of steps.

- We call σ a *stable misinformed equilibrium* ($\mathfrak{sme}$) the $\mathfrak{nme}$ that produces the same $\mathfrak{mG}$

Theorem

Every finite $\mathfrak{mG}$ has a $\mathfrak{sme}$.

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We have the NMEs:

- $\sigma_1 = ((1,0),(1,0))$, $\sigma_2 = ((0,1),(1,0))$

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- $\chi(\sigma_1) = \{(1, 1)\}$, $\chi(\sigma_2) = \{(2, 1)\}$.

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- $\chi(\sigma_1) = \{(1, 1)\}$, $\chi(\sigma_2) = \{(2, 1)\}$.
- σ_1 is a sme

Summary

- $\mathfrak{mG}$ A proposed unifying model for complex games
- $\mathfrak{mG}$ Study the inefficiency caused by misinformation
- $\mathcal{Ap}$ Analyse interaction between G^0 and G^is
- $\mathcal{Ap}$ $\mathfrak{nmes}$ and $\mathfrak{smes}$ capture a more "realistic" behavior

Conclusions

Open problems

Ppm How should we design utilities based on the different attitudes?

Ppm Can a combination of attitudes improve performance?

mG How should we design subjective views to achieve optimal performance?

mG What happens in cases where "subjectivity" has a structure?

Ap Can a more sophisticated update rule improve performance?

Open problems

- Ppm How should we design utilities based on the different attitudes?
- Ppm Can a combination of attitudes improve performance?
- mG How should we design subjective views to achieve optimal performance?

  [Varsos et al., *Coordination Mechanisms with Misinformation*, ICAART '22]
- mG What happens in cases where "subjectivity" has a structure?

  [Bitsaki, Varsos et al, *upcoming*]
- Ap Can a more sophisticated update rule improve performance?

Future directions/Ongoing

ERCIM CWI

- Ppm Implement new techniques, e.g. LP [Biló, '22]
- mG Derive tighter bounds regarding PoM
- mG Transfuse the idea to different classes of games
- mG/Ap Approximate methods for computing the outcome
- mG/Ap Adaptation vs Learning
- mG/Ap Integrate Epistemic theory, reasoning, and knowledge representation
- ∀ Utilize the information structure of the interactions

Conclusions

- Ppms and mGs are more realistic
- Subjectivity may improve the performance of a system
- Interactions are hardly ever one-shot, thus adaptation is desired

Conclusions

+ $\mathcal{P}pms$ and $\mathfrak{m}Gs$ are more realistic
+ Subjectivity may improve the performance of a system
+ Interactions are hardly ever one-shot, thus adaptation is desired

- Some counterintuitive results, e.g. altruism and $\mathrm{Po}A$ in $\mathcal{P}pms$
- In general, computational hardness in Ap, e.g. computation of $smes$

Thank you!

Discussion