On Group Activity Selection

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Introduction

Agents have to choose among multiple activities, with differing preferences over activities

Consider, e.g., a workshop whose organizers have to arrange social activities (e.g., hike, bus trip, and table tennis competition) for the free afternoon based on agents' preferences

- each agent can participate in at most 1 activity
  (due to cost reasons, or activities take place simultaneously)

First approach: elicit preferences over activities, divide agents into subgroups

Example

Use, e.g., plurality voting: Each agent names her favourite activity.
bus: 7 participants (high costs); table tennis: 48 p. (one table?!)

What if preferences depend on number of participants?

Introduction

- Idea: Exogenously add constraints on the group size.
  E.g., bus: ≥ 20 participants, table tennis: $2 \leq \#\text{participants} \leq 8$?
- Problem: preferences on the group size may differ
  E.g., senior faculty: bus trip with 10 people acceptable;
  students: at least 25 people per bus trip

leads to a more fine-grained approach GASP:

- elicit agents' preferences over pairs "(activity, number of participants)", and allocate agents to activities on basis of this information
- in general, agents' preferences can be considered weak orders over all such pairs (we consider the case of strict orders in the first part of the talk)
- possibility of non-participation in any activity: *void activity* $a_\emptyset$

Example

Let $N = \{1, 2, 3, 4, 5, 6\}$ and $A^* = \{a, b, c\}$. Let P be given as follows:

1	2	3	4	5	6
$(a, 6)$	$(c, 5)$	$(c, 6)$	$(c, 2)$	$(a, 1)$	$(b, 4)$
$(a, 5)$	$(a, 5)$	$(c, 5)$	$(b, 5)$	$(a, 5)$	$(a, 2)$
$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	$(a, 3)$	$(c, 3)$
$(c, 3)$	$(b, 4)$	$a_\emptyset$	$(b, 4)$	$(c, 6)$	$(c, 2)$
$a_\emptyset$	$a_\emptyset$	$(b, 5)$	$a_\emptyset$	$(c, 5)$	$a_\emptyset$
$(b, 5)$	$(c, 1)$	$(a, 4)$	$(a, 6)$	$(c, 4)$	$(b, 1)$
$(b, 6)$	$(b, 6)$	$(b, 6)$	$(b, 6)$	$a_\emptyset$	$(a, 6)$
$(a, 2)$	$(c, 6)$	$(b, 3)$	$(a, 2)$	$(c, 2)$	$(c, 2)$
$(a, 1)$	$(b, 2)$	$(c, 1)$	$(a, 1)$	$(c, 1)$	$(a, 4)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

- Goal: find a "good" assignment of agents to activities, when agents preferences depend on the activity and the number of participants in the activity (GASP)
- minimum requirement: no agent should be assigned to an alternative ranked below the void activity

GASP can be seen as

a voting problem or a coalition formation problem

Aim of this work:

- introduce solution concepts for such a setting,
  and analyze computational complexity involved in finding a solution
- consider aspect of manipulability

Formal Model of GASP

Instance (N, A, P) *of* GASP

- Set of *agents* $N = \{1, \dots, n\}$
- Set of *activities* $A = A^* \cup \{a_\emptyset\}$, where $A^* = \{a_1, \dots, a_p\}$, and $a_\emptyset$ is the *void activity*
- Set of *alternatives* $X = X^* \cup \{a_\emptyset\}$, where $X^* = A^* \times \{1, \dots, n\}$; alternative (a, k), $a \in A^*$, is interpreted as "activity a with k participants"
- *Profile* P, which consists of n *votes* (one for each agent): $P = (V_1, \dots, V_n)$.
  - For $i \in N$, vote V_i is a weak order over X

Formal Model of o-GASP

Instance (N, A, P) *of* o-GASP

- Set of *agents* $N = \{1, \dots, n\}$
- Set of *activities* $A = A^* \cup \{a_\emptyset\}$, where $A^* = \{a_1, \dots, a_p\}$, and $a_\emptyset$ is the *void activity*
- Set of *alternatives* $X = X^* \cup \{a_\emptyset\}$, where $X^* = A^* \times \{1, \dots, n\}$; alternative (a, k), $a \in A^*$, is interpreted as "activity a with k participants"
- *Profile* P, which consists of n *votes* (one for each agent): $P = (V_1, \dots, V_n)$.
    - For $i \in N$, vote V_i is a strict order $\succ_i$ over X

Basic Definitions

Solution to GASP:

Definition

An *assignment* for an instance (N, A, P) of GASP is a mapping $\pi : N \to A$.

- $\pi(i) = a_\emptyset$ means that agent i does not participate in any activity
- For $a \in A$, $\pi^a := \{i \in N | \pi(i) = a\}$
- For $i \in N$, $\pi_i := \{j \in N | \pi(j) = \pi(i)\}$

Minimum requirement: no agent should be assigned to an activity in a way such that she deems the corresponding pair "(activity, group size)" unacceptable

Definition

Given an instance (N, A, P) of GASP, an assignment $\pi : N \to A$ is

- *individually rational* if for every $a \in A^*$ and every agent $i \in \pi^a$ it holds that $(a, |\pi^a|) \succsim_i a_\emptyset$.
- *maximum individually rational* if π is individually rational and $\#(\pi) \geq \#(\pi')$ for every individually rational assignment π', where $\#(\pi) = |\{i \in N \mid \pi(i) \neq a_\emptyset\}|$

Maximum individually rational assignments

Example

Let $N = \{1, 2, 3, 4, 5, 6\}$ and $A^* = \{a, b, c\}$. Let P be given as follows:

1	2	3	4	5	6
$(a, 6)$	$(c, 5)$	$(c, 6)$	$(c, 2)$	$(a, 1)$	$(b, 4)$
$(a, 5)$	$(a, 5)$	$(c, 5)$	$(b, 5)$	$(a, 5)$	$(a, 2)$
$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	$(a, 3)$	$(c, 3)$
$(c, 3)$	$(b, 4)$	$a_\emptyset$	$(b, 4)$	$(c, 6)$	$(c, 2)$
$a_\emptyset$	$a_\emptyset$	$(b, 5)$	$a_\emptyset$	$(c, 5)$	$a_\emptyset$
$(b, 5)$	$(c, 1)$	$(a, 4)$	$(a, 6)$	$(c, 4)$	$(b, 1)$
$(b, 6)$	$(b, 6)$	$(b, 6)$	$(b, 6)$	$a_\emptyset$	$(a, 6)$
$(a, 2)$	$(c, 6)$	$(b, 3)$	$(a, 2)$	$(c, 2)$	$(c, 2)$
$(a, 1)$	$(b, 2)$	$(c, 1)$	$(a, 1)$	$(c, 1)$	$(a, 4)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

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$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	$(a, 3)$	$(c, 3)$
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$(b, 5)$	$(c, 1)$	$(a, 4)$	$(a, 6)$	$(c, 4)$	$(b, 1)$
$(b, 6)$	$(b, 6)$	$(b, 6)$	$(b, 6)$	$a_\emptyset$	$(a, 6)$
$(a, 2)$	$(c, 6)$	$(b, 3)$	$(a, 2)$	$(c, 2)$	$(c, 2)$
$(a, 1)$	$(b, 2)$	$(c, 1)$	$(a, 1)$	$(c, 1)$	$(a, 4)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

Special Cases

restrictions on agents' preferences that may simplify the problem of finding a good assignment

Definition

Consider an instance (N, A, P) of GASP. We say that the preferences of agent i are

- *increasing (INC)* if for all $a \in A^*$, $(a, k)_i \succsim_i (a, k-1)$ holds for each $k \in \{2, \ldots, n\}$.
- *decreasing (DEC)* if for all $a \in A^*$, $(a, k-1) \succsim_i (a, k)$ holds for each $k \in \{2, \ldots, n\}$.

We say that instance (N, A, P) has increasing/decreasing preferences, if each $i \in N$ has increasing/decreasing preferences.

Example

Let $A^* = \{a, b\}$ and $n = 9$. Consider agent i with vote V_i given by

$$(a, 9) \succ_i (a, 8) \succ_i (b, 9) \succ_i (a, 7) \succ_i (b, 8) \succ_i a_\emptyset \succ_i (b, 7) \succ_i (b, 6) \succ_i (a, 6) \ldots$$

Related Work

Group activity selection problem [joint w. E. Elkind, S. Kurz, J. Lang, J. Schauer, G. Woeginger; 2012]:

- model of GASP introduced
- approval-scenario a-GASP:
  - indifference between two alternatives an agent prefers to $a_\emptyset$
  - focus laid on *maximum individually rational assignments* and stability notions (also w.r.t. increasing/decreasing preferences)

Group activity selection from ordinal preferences [D., 2015]:

- o-GASP introduced
- computational complexity of finding stable assignments respectively maximizing k-approval scores

This talk follows up these works in two ways:

- Applying different solution concepts for o-GASP
- Considering aspects of manipulability in finding maximum individually rational assignments

Related Work

Hedonic games [Banerjee et al., 2001; Bogomolnaia & Jackson, 2002]:

- each agent i has preferences over the subsets of agents containing i
- GASP can be embedded in that framework
- hardness results for anonymous and non-anonymous hedonic games w.r.t. stability notions such as Nash, core, (contractual) individual stability known [Ballester, 2004]
- Finding a Pareto optimal solution is NP-hard for both non-anonymous and anonymous hedonic games [Aziz et al., 2013]

Solution Concepts for o-GASP

Different approaches to find a “good” outcome:

1. Borda scores
2. Condorcet criterion
3. Pareto optimality

Approval and Borda scores

$f(\pi) := \sum_{i \in N} f_i(\pi(i), |\pi_i|)$ with $f_i : X \rightarrow \mathbb{R}_0^+$. The value $f(\pi)$ is called *score of* π.

- In *approval scores*, for $i \in N$, let $f_i(x) = 1$ if $x \succ_i a_\emptyset$ and $f_i(x) = 0$ otherwise.
  k-approval scores, $k \in \mathbb{N}$, correspond to approval scores in the case that $|\{x \in X : x \succ_i a_\emptyset\}| = k$ holds for all $i \in N$.
- In *Borda scores*, for $i \in N$ we have $f_i(x) = |\{x' \in X : x \succ_i x'\}|$.

Goal: find an individually rational assignment that maximizes the total score

Condorcet & Pareto optimal assignments

Definition

Given an instance (N, A, P) of o-GASP,

- we say that agent i *prefers* assignment π over assignment π' (denoted by $\pi \rhd_i \pi'$), if $(\pi(i), |\pi_i|) \succ_i (\pi'(i), |\pi'_i|)$ holds.
- An assignment π is *IR-Condorcet*, if π is individually rational and for all individually rational assignments $\pi' \neq \pi$ we have $|\{i \in N : \pi \rhd_i \pi'\}| > |\{i \in N : \pi' \rhd_i \pi\}|$.
- π is *MIR-Condorcet*, if π is maximum individually rational and for all maximum individually rational assignments $\pi' \neq \pi$ we have $|\{i \in N : \pi \rhd_i \pi'\}| > |\{i \in N : \pi' \rhd_i \pi\}|$.
- an individually rational assignment π is *Pareto optimal* if there is no assignment π' such that there is no $i \in N$ with $\pi \rhd_i \pi'$ and for at least one $j \in N$ we have $\pi' \rhd_j \pi$.

Results: Approval and Borda scores

- *k-approval* [D., 2015]:

	general pref.	INC	DEC
$k = 1$	in P	in P	in P
$k \in \{2, 3\}$	NP-c		in P
$k \geq 4$	NP-c		NP-c

- *Borda:*

	general pref.	INC	DEC
Borda	NP-c	NP-c	NP-c

Results: Condorcet solution & Pareto optimality

	general pref.	INC	DEC
IR-Condorcet-Existence	coNP-hard	coNP-hard	in P
MIR-Condorcet-Existence	coNP-hard	coNP-hard	?
Determine a Pareto opt. ass.	in P		

Easiness results

IR-Condorcet-Existence.

In the case of decreasing preferences, an assignment π is IR-Condorcet $\Leftrightarrow$ $\pi(i) = a_i$ for top-ranked alternative $(a_i, 1)$ in $\succ_i$.

Easiness results

Pareto Optimality.

Simple observation: For each agent i with top-ranked alternative (a, k), there is a Pareto optimal assignment π that assigns i to a such that $|\pi^a| = k$ (if there are at least k agents who prefer (a, k) to $a_\emptyset$).

Basic algorithmic idea:

- First, pick an arbitrary agent i with top-ranked alternative (a, k) and assign agent i to a together with $k - 1$ arbitrarily chosen other agents that prefer (a, k) to $a_\emptyset$.
- Try to find an individually rational assignment that has i, and in total k agents, assigned to a and is better for at least one agent while no one gets assigned to a worse-ranked alternative.

Easiness results

Pareto Optimality.

More generally, the algorithmic idea can be summarized as:

- Consider an individually rational assignment in which
  (i) for some agents the activities they are assigned to and
  (ii) for some activities the number of agents assigned to the activity have already been fixed.
- Pareto-improve the assignment, i.e., find an assignment that respects (i) and (ii) and is better for at least one agent while making no agent worse off (this improvement-step can be performed by solving a flow problem with lower and upper edge capacities).

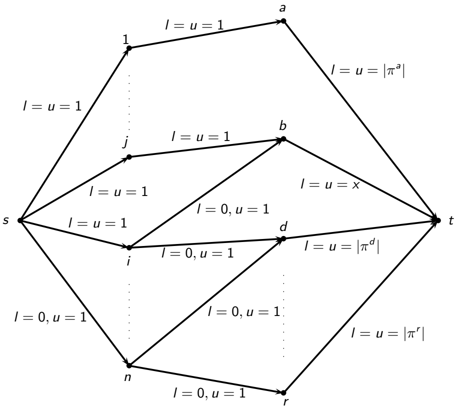
Easiness results

Pareto Optimality: *Improvement-step.*

Given an assignment π, agent j and alternative (b, x), such that

- fixed: $\pi(1) = a$ and the number of agents assigned to a, d, r
- $\pi(i) = d$, $(b, x) \succ_i (d, |\pi^d|)$; $\pi(n) = a_\emptyset$, and $(d, |\pi^d|) \succ_n a_\emptyset$, $(r, |\pi^r|) \succ_n a_\emptyset$

Can we "Pareto-improve" by assigning j to b (with group size x)?



Manipulability in GASP: maximum individually rational assignments

Issue of manipulability in maximum individually rationality in GASP

Example

Let $N = \{1, 2, 3, 4, 5, 6\}$ and $A^* = \{a, b, c\}$. Let P be given as follows:

1	2	3	4	5	6
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$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	$(a, 3)$	$(c, 3)$
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$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	$(a, 3)$	$(c, 3)$
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$(a, 5)$	$(a, 5)$	$(c, 5)$	$(b, 5)$	$(a, 5)$	$(a, 2)$
$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	~~$(a, 3)$~~	$(c, 3)$
$(c, 3)$	$(b, 4)$	$a_\emptyset$	$(b, 4)$	$(c, 6)$	$(c, 2)$
$a_\emptyset$	$a_\emptyset$	$(b, 5)$	$a_\emptyset$	$(c, 5)$	$a_\emptyset$
$(b, 5)$	$(c, 1)$	$(a, 4)$	$(a, 6)$	$(c, 4)$	$(b, 1)$
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$(a, 1)$	$(b, 2)$	$(c, 1)$	$(a, 1)$	$(c, 1)$	$(a, 4)$
⋮	⋮	⋮	⋮	⋮	⋮

Manipulability in GASP: maximum individually rational assignments

Issue of manipulability in maximum individually rationality in GASP

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$(b, 4)$	$(a, 6)$	$(b, 4)$	$(a, 2)$	$(a, 4)$	$(c, 4)$
$(a, 2)$	$(a, 3)$	$(c, 3)$	$(a, 3)$	~~$(a, 3)$~~	$(c, 3)$
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$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

Manipulability in GASP: maximum individually rational assignments

Given instance $\mathcal{I} = (N, A, P)$ of GASP with set N of agents and set A of activities

- $\Pi(\mathcal{I})$ denotes set of maximum individually rational assignments in $\mathcal{I}$.
- $\mathcal{S}(N, A)$ denote set of all instances of GASP with agent-set N and activity-set A,
- $\alpha(N, A) := \{\pi | \pi : N \to A\}$ is set of assignments of agents in N to activities in A

Definition

Given an instance $\mathcal{I} = (N, A, P)$ of GASP,

- The mapping $C : \mathcal{S}(N, A) \to 2^{\alpha(N,A)}$ with $C(\mathcal{I}) = \Pi(\mathcal{I})$ is called *mir-aggregation correspondence*.
- We call a function $f : \mathcal{S}(N, A) \to \alpha(N, A)$ with $f(\mathcal{I}) \in \Pi(\mathcal{I})$ *mir-aggregation function*.

Manipulability in GASP: maximum individually rational assignments

Single-valued aggregation function:

Definition

An mir-aggregation function f is called *manipulable*, if there exist an instance $\mathcal{I} = (N, A, P)$, an agent $i \in N$ and a profile P' with $P|_{N\setminus\{i\}} = P'|_{N\setminus\{i\}}$ such that, with $f(\mathcal{I}) = \pi$, $\mathcal{I}' = (N, A, P')$ and $f(\mathcal{I}') = \pi'$,

$$\pi' \rhd_i \pi$$

holds. f is called *strategyproof*, if f is not manipulable.

Manipulability in GASP: maximum individually rational assignments

Multi-valued aggregation correspondence: Consider Preference extensions.

E.g.,

Definition

The *maxi-max extension* is defined by: for $i \in N$ and $X, Y \in 2^{\alpha}$, $X \succsim_i^{max} Y$ iff for $x \in \max_i X$, $y \in \max_i Y$, $(x \trianglerighteq_i y)$ holds.

Analogously, the *maxi-min extension* is defined by: for $i \in N$ and $X, Y \in 2^{\alpha}$, $X \succsim_i^{min} Y$ iff for $x \in \min_i X$, $y \in \min_i Y$, $(x \trianglerighteq_i y)$ holds.

Manipulability in GASP: maximum individually rational assignments

Multi-valued aggregation correspondence: Consider Preference extensions.

E.g.,

Definition

Gärdenfors extension:
For $i \in N$ and $X, Y \in 2^{\alpha}$, $X \succsim_i^{\mathcal{G}} Y$ if one of the three following conditions is satisfied:

1. $X \subset Y$ and for all $x \in X$, $y \in Y \setminus X$ we have $x \trianglerighteq_i y$.
2. $Y \subset X$ and for all $x \in X \setminus Y$, $y \in Y$ we have $x \trianglerighteq_i y$.
3. neither $X \subset Y$ nor $Y \subset X$ and $(x \trianglerighteq_i y)$ for all $x \in X \setminus Y$, $y \in Y \setminus X$.

Manipulability in GASP: maximum individually rational assignments

Multi-valued aggregation correspondence C

Definition

Let ε be a preference extension. C is ε-*manipulable* if there exist an instance $\mathcal{I} = (N, A, P)$, an agent $i \in N$ and a profile P' with $P|_{N\setminus\{i\}} = P'|_{N\setminus\{i\}}$ such that, with $\mathcal{I}' = (N, A, P')$,

$$\Pi(\mathcal{I}') \succ_i^{\varepsilon} \Pi(\mathcal{I})$$

holds. C is ε-*strategyproof*, if C is not ε-manipulable.

Manipulability in GASP: Results

1 **simple activity**

- bad news: manipulable
- increasing preferences: strategyproof
- decreasing preferences:
  - every mir-aggregation function is manipulable
  - mir-correspondence C is maxi-min strategyproof, but Gärdenfors- & maxi-max-manipulable

Manipulability in GASP: Results

~~1~~2 **simple activities**

- bad news: manipulable
- increasing preferences: ~~strategyproof~~ manipulable
- decreasing preferences:
  - every mir-aggregation function is manipulable
  - mir-correspondence C is maxi-min ~~strategyproof~~ manipulable, and Gärdenfors- & maxi-max-manipulable

Manipulability in GASP: Results

preferences, activities	*extension*		
	Gärdenfors	Maxi-max	Maxi-min
decreasing, 1 simple	man	man	sp
decreasing, 1 copyable	man	sp	man
decreasing, 2 simple	man	man	man
decreasing, 2 copyable	man	sp	man
increasing, 1 simple	sp	sp	sp
increasing, 1 copyable	man	sp	man
increasing, 2 simple/copyable	man	man	man

Table: Overview over the results regarding manipulability of correspondence C w.r.t. different preference extensions.

Conclusion and Outlook

We have

- obtained complexity results for different solution concepts in o-GASP
- considered manipulability in GASP

Future research (GASP):

- further solution concepts for o-GASP
- open complexity issues

Outlook

- Novel domains
- Concepts too strict?
- Approximation Algorithms/Hardness
- Fixed Parameter Tractability