Stable Beneficial Group Activity Formation

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Abstract—**Computational models are one of the very powerful tools for expressing everyday situations that are derived from human interactions. In this paper, an investigation of the problem of forming beneficial groups based on the members' preferences and the coordinator's own strategy is presented . It is assumed that a coordinator has a good intention behind trimming members' preferences to meet the ultimate goal of forming the group. His strategy is justified and evaluated by Nash stability. There are two variations of the problem: the Anonymous Stable Beneficial Group Activity Formation and the General Stable Beneficial Group Activity Formation. The computational complexity of solving both variations has been analyzed. Finding stable groups needs non-polynomial time algorithm to be solved. A polynomial time solution is presented and enhanced with examples.**

Keywords—computational models; group formation; members' preferences; Nash stability

I. INTRODUCTION

Capturing human behavior and translating it into a model has been the area of research since centuries. The motivation was to build systems that can percept, learn, adapt and take right decisions as well as predict future actions.

This seed plants itself deeply into science, it produced rich mathematical social sciences that had empowered the introduction of social computing science.

Many powerful systems were created as the result of merging social behavior and computational models, examples are: emails, social networks, online gaming, political parties formation, healthcare systems, speaker identification, query expansion techniques [1][7][17],etc.

One of the most interesting areas in this perspective is collective intelligence that refers to the kind of intelligence that is aroused as an effect of the collaborative efforts of many agents to achieve a single goal taking into account competition among them [11]. This concept (although not so named) was referred to in Hedonic Coalitions that was introduced in 1980 [6]. It considered how social coalitions are structured to meet certain preferences. A concept that is rooted in the work of Marquis de Condorcet in 1785, who investigated the probability of making a correct decision by the cooperation of several members [5]. Figure 1 shows the fields of science that branches from collective intelligence [18][12].
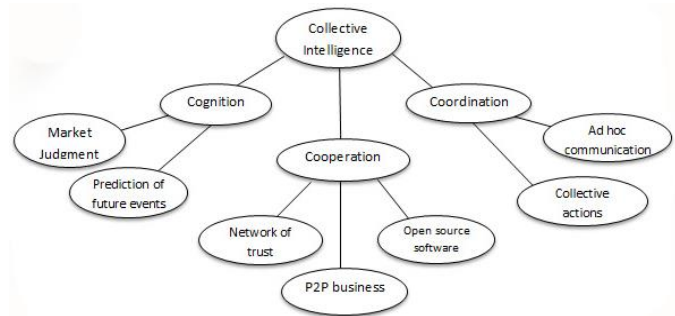

Fig. 1. Collective Intelligence Branches

In the scope of this paper, an investigation of the area of beneficial group activities formation that can be classified under coordinating collective actions is presented.

Scheduling a set of activities has been studied thoughtfully in the literature; one of the new trends in this field is how to schedule activities that each of them should compromise a set of agents.

To formulate this problem, let's consider the social situation that an event coordinator is trying to organize multiple distributed activities that are held in different places at different time intervals. There are no precedence relationship between these activities. They are supposed to be independent on each other; they don't share the same resources.

The coordinator's responsibility is to invite/assign one or more agent to each activity. Agents are not considered as peers rather each agent is supposed to contribute in that activity by a certain score/weight/benefit. Thus, the organizer's goal is to invite/assign as many agents as possible to maximize the amount of contribution i.e. benefit of the activity.

The coordinator should consider the agents' preferences for both the activity and the number of participants in that activity, thus the coordinator should assign agents to activities on basis of their preferences over group size.

Each agent is allowed to have preferences over the identities of other invitees, e.g. one agent might only come if his/her colleague is coming and may not prefer to come if a competitor agent comes.

The coordinator should make sure that each agent's preferences are met but without contradicting with the ultimate goal of forming the group i.e. maximizing benefit.

Consider the situation where a professor is trying to create multiple research groups on different topics within his field, for example. One of the main concerns when forming such assignments is Stability. It is desirable in many systems that contain scheduling, QoS, clustering, data mining [2][14][16], pattern matching [15], etc. But, it is not always possible to maintain a stable assignment. This motivates investigating the problem and evaluating the complexity of finding a feasible solution.

The paper is organized as follow: Section II presents related literature. Section III demonstrates the Stable beneficial Group Activity Formation Problem. The Anonymous variation of the problem is investigated in section IV along with definitions and notations in addition to examples and algorithms to solve the problem. Section V introduces the Stable beneficial Group Activity Formation Problem along with its definitions, example and algorithm. The conclusion is given in section VI.

II. RELATED LITRETURE

Group formation itself has been studied thoughtfully in the literature, different algorithms were proposed to best cluster the members into groups based on attributes they hold [13].

The General Group Activity Selection Problem (GASP) was formally introduced in [4]. An organizer tries to organize several activities, each activity is accomplished by several agents. An agent can participate in exactly one activity at a time, the agent is allowed to select an activity to participate in and the preferred group size for that activity. The authors analyzed the computational complexity of this problem in different cases.

The authors in [8] introduced the Stable Group Scheduling Problem where an organizer is trying to schedule an event that happens over multiple time slot. An agent is allowed to choose the desired time slot to join event and the preferred group size for the activity in that time slot. They analyzed the complexity of this problem for both the non-strategic agents (i.e. agents that reveal their preferences without further modifications) and strategic agents (agents that may change their preferences afterwards).

They found that for the non-strategic agent's variation, a polynomial time algorithm that determines whether a stable schedule exists, and if it does, determine the maximum number of schedules exist.

They extend their work in [9], by introducing the *Stable Invitation Problem* in two variations: the anonymous and non-anonymous. They consider the problem of how to invite multiple agents to a single event taking into account their preferences over a number of invitees; and who the invitees are. They provide a number of complexity results with respect to stability, and also consider strategic behavior of the agents.

In [3], Darmann re-introduced the General Group Activity Selection Problem, considering the agents' ordinal preferences

where each agent can determine the (activity, group size) pair. He analyzed the computational complexity for finding a stable assignment using k-approval scores and considering Nash and core stability.

The approach in this work differs from the approaches stated above by considering the situation of more than one independent activity. To best reflect the problem, the organizer himself has a goal to form the group/invitation which is maximizing benefit. Furthermore, in this approach the agents are not treated as peers, instead, each agent is assumed to contribute in the group to some extent.

It is worth mentioning that these problems are inspired by the Hedonic Games [6].

III. STABLE BENEFICIAL GROUP ACTIVITY FORMATION PROBLEM

A professor creates multiple research groups on different topics within his field, he/she invites students to join these groups. His/her objective is to maximize the benefit from this group by:

1) maximizing the number of attendees in each group.
2) inviting only students that has knowledge in the area.

Students are allowed to have preferences over the group size as well as the colleagues in the group. The professor's strategic considers Nash stability in forming stable groups. There are two variations of the problem, the Anonymous Beneficial Group Activity Formation ABGA and the General Beneficial Group Activity Formation GBGA.

IV. ANONYMOUS BENEFICIAL GROUP ACTIVITY FORMATION ABGA

In this variation, students don't have preferences over identities of the invitees but they only care about the size of the research group they are invited into.

A. Definitions and Notations

Definition 1. An instance of the Beneficial Group Activity Formation ABGA is a tuple (A, E, P) where,

A = $\{a_1, a_2,\ldots,a_n\}$ is a set of n agents,

E = $\{e_1, e_2, \ldots, e_m\}$ is a set of m activities (Research Groups)

P is an n-tuple of preferences of agents where P = (P_1, P_2,…, P_n). For each agent a_i,, define P_i to be a total preorder ($\succeq_i$) on the set of preferences, the agents may prefer not coming if $p_i=0$.

For any $p_1, p_2 \in (P\backslash\{0\})$, $p_1 \succeq_i p_2$ means that agent a_i prefers joining the group if the number of attendees in the group is p_1 (including himself) to attending if the number of attendees is p_2 attendees (including himself).

Any subset of A is a solution to ABGA-instance (N,E,P), is called G a 'Beneficial Group'.

Definition 2. Agent's benefit, in this example, student's knowledge within the area of the group is defined in terms of (courses studied , interest , publications) and is expressed as a score in the knowledge-matrix. The higher the score is, the

more knowledge the student has within this area. Knowledge matrix B is a two-dimensional matrix of size ($|A|*|E|$) i.e.($n*m$). The professor invites all students that are expected to maximize the contribution of the group, by inviting only students whose knowledge within the area of the group exceeds T, a threshold score determined by the professor.

$\forall$ $a_i \in G$, $B(a_i, E_j) > T$.

Definition 3. The objective is to invite a subset of agents subject to stability constraints considering agents' preferences over group size. An instance (A, E, P) is said to be Nash stable, if:

1) If everyone who's invited is willing to participate, then G is Individually-Rational.

G is Individually-Rational (IR) if $\forall a_i \in G$, $|G| \geqslant 0 \wedge B(a_i, E_k) > T$.

2) If everyone who's not invited is unwilling to join, G is Regret-Free RF if $\forall a_i \notin G$, $0 \geqslant (|G| + 1)$.

In other words, Individual-Rationality means that all the invited students prefer to come to not coming and has knowledge in the area of the research group as their contribution exceeds T. While Regret-Free means that all agents who are not invited, don't prefer to come.

G is said to be Nash stable if it is both IR and RF.

The professor's goal is to maximize the number of members in stable beneficial groups.

B. Examples of ABGA

Example1.Example of anonymous preferences.

- A Basketball team preferences over group size.

  A1: $10 \succ 5 \succ 0 \succ 1,2,3,4$ [1]
- A Soccer team preferences over group size.

  A2:$22 \succ 11 \succ 0 \succ 1,2,3,4,5,6,7,8,9,10$

Example2.Finding a Stable Group.

Consider agents a_1, a_2, $a_3$have knowledge in two areas and the professor is trying to compose two Research GroupsG_1 and G_2. The students preferences over group size are as follows:

- P_1: $1 \succ 0 \succ 2$
- P_2: $3 \succ 0 \succ 1$
- P_3: $2 \succ 0 \succ 1$

- Inviting no one, i.e. G={}, is not RF because of a_1 whose preference is ($1 \succ 0$), he prefers coming alone to not coming at all.

Recall that G is RF if $\forall a_i \notin G$, $0 \geqslant (|G| + 1)$

- Inviting only a_1, i.e. G={a_1} is not RF because of a_3 whose preference is ($2 \succ 0$), he prefers joining someone

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[1]a1 prefers joining the basketball team if the number of members (including himself) is 10, more than he prefer joining if the members (including himself) is 5. And he also prefers joining the team if the number of members (including himself) is 5, more than not coming. And he would rather not come if the number of members (including himself) is less than 5.

else to not coming. Investigate G={a_2,a_3}, if it is stable, then G={a_1} is stable.

G_1={a_2,a_3}is stable because it is both IR and RF. Thus G_2={a_1} is stable.

- Inviting only a_2, i.e. G={a_2} is not IR because of a_2 whose preference is ($0 \succ 1$), he would rather not come to coming alone.

- Inviting only a_3, i.e. G={a_3} is not IR because of a_3 ($0 \succ 1$)

- Inviting a_1,a_2, i.e. G={a_1,a_2} is not IR because of a_1 preference ($0 \succ 2$), he prefers not coming to coming with only another person.

- Inviting a_1,a_3, i.e. G={a1,a2} is not IR because of a1.

- Inviting a_1,a_2, i.e. G={a_1,a_2} is not IR because of a_1.

- It is not possible to invite the three of them as it contradicts the professor's constrain of constructing two groups.

Thus, only one assignment is possible.

G1={a_2,a_3} and G2={a_1}.

Example2.Stable Group may not exist

Consider studentsA_1 and $A_2$are invited to only one Research Group E_1. Students preferences over group size are as follows:

- P_1: $1 \succ 0 \succ 2$
- P_2: $2 \succ 0 \succ 1$
- Inviting no one, i.e. G={}, is not RF because of $a_1$preference ($1 \succ 0$)

- Inviting only a_1, i.e. G={a_1} is not RF because of a_2 preference ($2 \succ 0$).

- Inviting only a_2, i.e. G={a_2} is not IR because of a_2 preference ($0 \succ 1$)

- Inviting a_1,a_2, i.e. G={a_1,a_2} is not IR because of a_1 preference ($0 \succ 2$)

C. ABGA Algorithm and Complexity Analysis

1) Exhaustive Algorithm Complexity

Algorithm 1: To find the maximum number of stable groups

Input:
1. A set of students.
2. P Students' preferences as tuples.
3. E set of Research Groups.
4. B knowledge matrix.
5. T knowledge threshold.
Output: BG a subset of A
{ // Definitions
    int n   // number of students
    int m   // number of activities

```
        int p                // size of preferences tuple
        int Students[n] //1-dimension array of students
        int Activity[m]  // 1-dimension array of activities
        int Benefit[n,m]
        int Pref[n,p]      // preferences matrix
        G[ ], S[ ]         // temporary vectors
   // Groups construction
        For j = 1 to m
        For i= 1 to n
                If ( B(i , j) > T )
                        Then Students[i] ∈ G_j[]
   //Checking size compatibility of each group
        For j = 1 to m
                PSize_j= |G_j|  // preferred size of group
                For i= 1 to PSize_j
                {
                {
                For j= 1 to n
                For k= 1 to p
                If (i = Pref[j,k] then  Students[n]  ∈S_i[ ]
                }
                If |S_i[ ]| = PSize_j then S_i⊂ BG_j
                }
        Return BG_j
        }
}
```

To check whether a group G is stable, assuming that the professor invited only beneficial students, consider:

- $\forall a_i \in G$, check whether $|G| \succcurlyeq_i 0$

- $\forall a_i \notin G$, check whether $0 \succcurlyeq_i (|G| + 1)$

This checking is repeated at most $|A|*|E|$ times, i.e. for each of the agents and groups.

Thus to check all the 2^n subsets of A, the algorithm's complexity takes at most $O(n*m*2^n)$ which means that the algorithm needs non-polynomial time to find the solution.

2) Efficient Algorithm Complexity

It is possible to check whether a group G is stable, assuming that the professor invited only beneficial students, then consider Algorithm 2:

Algorithm 2: To find the maximum number of stable groups

Input:
1. A set of students.
2. P Students' preferences tuple.
3. G set of Research Groups.
4. A professor's preferred group size X.

Output: G a subset of A

```
{  For j = 1 to m
 For i= 1 to n
 If {Students[i] ∈G_i : (X ≽_j 0)}≥ X
 If {Students[i] ∈G_i: (0 ≽_j X)Λ ((X+1) ≽_j 0) } = 0
 If {Students[i] ∈G_i: (X ≽_j 0)Λ ((X+1) ≽_j 0) } ≤ X
        Return G_i is stable
```

}

This algorithm takes only $O(m*n^2)$ operations which is so much better than the exhaustive search algorithm.

V. GENERAL BENEFICIAL GROUP ACTIVITY FORMATION PROBLEM GBGA

This is a generalization of the ABGA. In addition to group size, each student allowed to have preferences over the identities of the colleagues joining the same group:

- Colleagues who is comfortable working with: *Wish list*

- Colleagues who is undesirable working with: *Reject list*

The professor strategic is to consider Nash stability in forming stable groups. His/her objective is to maximize the benefit from this group by:

1) maximizing the number of attendees in each group.
2) inviting only students that has knowledge in the area.

A. Definitions and Notations

An instance of the General Group Activity Formation ABGA is (A, E, P= (P_1, P_2,…, P_n), W,R), where

A = {a_1, a_2, …, a_n} is a set of agents.

E = {e_1, e_2, …, e_m} is a set of m activities (Research Groups)

P is an n-tuple of preferences of agents where $P = (P_1, P_2,…, P_n)$. For each agent a_i, define P_i to be a total preorder ($\succcurlyeq_i$)on the set of preferences, the agents may prefer not coming if $p_i=0$.

W_i is prefer set of student a_i where $W_i \subset A$

R_i is reject set of student a_i where $R_i \subset A$

Any subset G of A is a solution to GBGA-instance(A,E,P,W,R), G is a `Beneficial Group'∎

Students are allowed to have preferences over:

- Research group size
- Colleagues who is comfortable working with: W-list
- Colleagues who is undesirable working with: R- list
  Thus, every potential invitee is either:

- Original-Invitee: invited by the professor as he/she has knowledge within the area or

- Co-Invitee: preferred to be invited by one of the original-invitees as they both have mutual contribution within the area or for any other reasons.

Everyone who is not invited, is not a researcher in the area.

Agents Mutual contribution matrix is defined in terms of two-dimensional matrix M of size (n * n) that represents mutual contribution between agents based on (shared project, publications).

B. Applying Stability Constrains

The professor's ultimate goal is to collect beneficial students in each group to attain group stability. Although he

invites only students that has a contribution in the area above a certain threshold, he would agree with an original-invitee to invite a student with less contribution if this co-invitee has previous mutual contribution with the original invitee.

This strategy is adopted from May and Doob work on cooperative learning. They stated that "people who cooperate and work together to achieve shared goals, were more successful in attaining outcomes, than those who strived independently to complete the same goals" [10]. Thus, the professor is willing to:

- not respond to the student's wish to work with a certain colleague if the co-invitee has no knowledge in the area. The professor would agree to invite the co-invitee student a_i if his/her contribution within the area of the group is more than T.

If $a_i \in W_{j,k} \wedge B(a_i, E_k) > T$, then $a_i \in G_j$, where

a_i is the co-invitee student

$W_{j,k}$ is the Wish-list of Student j for activity K

$B(a_i, E_k)$ is the benefit of student a_i for the activity E_k

T is the contribution threshold.

- not respond to the student's wish to reject working with a certain colleague, if the rejected college has knowledge in the area.

If $a_i \in R_{j,k} \wedge B(a_i, E_j) > T$, then $a_i \in G_j$,

where $R_{j,k}$ is the Reject-list of Student j for activity K

- agrees on the student's wish to work with a certain colleague, if the co-invitee has mutual contribution with the original-invitee even if his/her contribution within the area is < T.

If $a_i \in W_{j,k} \wedge (B(a_i, E_j) < T) \wedge (M(a_i, a_j) > T')$, then $a_i \in G_j$

Where T' is a mutual contribution threshold determined by the professor.

C. GBGA Example

A professor is trying to create 3 research groups for 3 areas. He/she has 3 students. The contribution threshold is >4. The mutual contribution threshold is >2. Find the maximum number of groups. The students preferences, contribution and mutual contribution is shown in the matrices in TABLE II.

TABLE I.   MUTUAL CONTRIBUTION MATRIX M

Agent	a1	a2	a3
a1	0	1	5
a2	1	0	7
a3	5	7	0

TABLE II.   CONTRIBUTION MATRIX B

Agent	Area1	Area2	Area3
a1	9	2	7
a2	1	4	3
a3	6	2	10

TABLE III.   PREFERENCES MATRIX

Student	Preferred group size	Prefer List	Reject List
a_1	3>2>0	a_2	a_3
a_2	2>1>0	a_3	0
a_3	4>2>0	a_1	a_2

It is obvious that the preferred size that the three students agree upon is 2.

For Area1,

- Students a_1 and a_3 have acceptable contribution scores, they both would be invited.
- a_1W-list is rejected, because a_2 has little contribution in the area and little mutual contribution with a1.
- a_1W-list is rejected, because a_3 has good contribution in the area.
- a_3W-list and R-List are applicable.
- The resultant group is G1={a_1,a_3}.

For Area2,

- Only students a_2 has acceptable contribution score, he is invited, G_2={a_2}.
- A_2W-list is accepted as a3 has mutual contribution with a_2>2. Thus, G_2={$a_2.a_3$}.
- A_2 R-List is empty.
- The resultant group is G_2={A_2,A_3}.

For Area3,

- Students a_1 and $a_3$have acceptable contribution scores, they both would be invited.
- a_1W-list is rejected, because $a_2$has little contribution in the area and little mutual contribution with a_1.
- a_1W-list is rejected, because $a_3$has good contribution in the area.
- a_3W-list and R-List are applicable.
- The resultant group is G_1={a_1,a_3}.

D. GBGA Algorithm and Complexity Analysis

Algorithm: To find the maximum number of stable groups.

Input:
1. A set of students.
2. P Students' preferences matrix P.
3. E set of Research Areas.
4. Wish-List W
5. Reject-List R
6. Contribution matrix B
7. Mutual Contribution matrix M.

Output: a subset of BG∈G

```
{ // Definitions
        int n              // number of students
        int m              // number of activities
        int p              // size of preferences tuple
        int Students[n]    //1-dimension array of students
        int Activity[m]    // 1-dimension array of activities
        int Benefit[n,m]
        int Pref[n,p]      // preferences matrix
        G[ ], S[ ]         // temporary vectors
```

$PSize_j = n$

For i= 1 to n

For k= 1 to p

{

      For j= 1 to n

      If ($PSize_j$ = Pref[j,k]) then Students[j] $\in$ S_i[ ]

      If |S_i[ ]| = $PSize_j$ then $S_i \subset G_j$

}

For k= 1 to m

For i= 1 to |G_i[ ]|

For j= 1 to |G_i[ ]|

  if (Students[i] $\in W_k \wedge$ B(i , k) > T) then Students[i]$\in G_j$

  else

If (Students[i] $\in R_k \wedge$ B(i , k) > T) then Students[i]$\in G_j$

else

If (Students[i]$\in W_k \wedge$ (B(i , k) < T) $\wedge$ M(Students[i] ,Students[j])>T') then Students[i]$\in G_j$

Return G

}

The GBGA algorithm takes only $O(m*n*p)$ operations. It has a polynomial run time complexity.

VI. Conclusion and Discussion

The main contribution of this work is the analysis of the stable beneficial group activity formation problem considering the members' preferences as well as the coordinator strategy. The coordinator is trying to maintain stability in the groups formed while maximizing the overall benefit and balance those metrics to the members' preferences. The formalism of this problem tried to reflect the natural way of composing beneficial groups without relying upon hard constrains in the traditional way. Two variations of the problem and a their computational complexity are presented.

The proposed algorithm, with polynomial running time achieves the same quality of the exhaustive non-polynomial time algorithm that is used for stable beneficial groups formation. The proposed solution made use of the agents' preferences and coordinator's strategy as delimiters of the problem space.

For future research, it is highly encouraged that the researchers formulate the reflection of further extensions of the problem. Examples of extensions are scheduling those groups in different time slots, considering deadline constrain, and forcing penalties on members who change their group membership, etc.

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