Measuring Synergy from Benevolence in a Network Organization

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Abstract

In a complex adaptive system, diverse agents perform various actions without adherence to a predefined structure. The achievement of joint actions will be a result of continual interactions among them that shape a dynamic network. Agents may form an ad hoc organization based on dynamic network of interactions for the purpose of achieving a long term objective, which is called a *Network Organization* (NO). For the dominant influences of the network substrate in an NO, multiple effects of it have an impact on the NO behaviors and directions. We envisioned several dimensions of such effects to be synergy, social capital, externality, influence, etc. The focus of this paper is on measuring *synergy* as one of those possible network effects. Synergy describes different modalities of compatibility among agents when performing a set of coherent and correspondingly different actions. When agents are under no structural obligation to contribute, synergy is quantified through multiple forms of serendipitous agent chosen benevolence among them. The approach of this paper is to measure four types of benevolence and the pursuant synergies from them stemming from agent interactions. We exemplify this approach using a case study of a multiplayer online game.

Agents of an open Multi-Agent Systems (MAS) are self-governed by their own belief systems. Common actions allow agents to engage in social interactions with one another. It is prevalent for them to behave impulsively to cope with certain exigencies (Alqithami and Hexmoor 2014a). When they are organized for a long term objective, repeated pattern of interactions among them shape a feature of their organizational structure. It is possible for an organization to exhibit a specific feature yet not characterized by it. Such features include arrangements and interaction protocols that characterize working relationships among a group of individuals (Horling and Lesser 2004). For the prevalence of network in such organizations, the notion of *Network Organization* (NO) was introduced to present large, semi-autonomous, ad-hoc networked individual entities that aim to automate command and control of distributed complex objectives (Alqithami and Hexmoor 2015). For this, an NO is applied here as testbed to incapsulate an open MAS functioning over common objectives.

NOs have produced significant impacts on formation and functioning of human organizations. Human populated NOs benefit from their collective pool of knowledge and skills as well as a spring of common social traits, such as trust and beneficence. We focus on the artificial model of agents based NOs that no doubt will possess features inspired by humans' NOs; however, there are remaining profound differences. The artificial NOs lack temporal history and are volatile when addressing specific problem. On the other hand, humans' NOs benefit from their shared histories. Even highly dynamic humans' NOs will possess temporal resilience that is not available in artificial NOs. An NO is an ubiquitously open model that includes transparent entry and exit to the organization. Location ignorance is extended to permit temporal freedom that allows asynchronous control of operations. Another extension is to allow any credentialed network member node to exert influence on operations.

The focus of this paper is on the dynamic scale of interactions in an NO, where it is challenging to predict the values of their connections. A paradigmatic view of the intra-NO, which is presented in (Alqithami and Hexmoor 2015), capitulates representational power of a more ubiquitous perspective over its modifier by providing guidelines, a reference model, and a set of principles. This paradigm manifests a network perspective over all aspects of an NO as a guidelines for modeling organizations of large firms working on complex problems. We benefit from the NO paradigm for further elaboration in our discussions as it identifies profiles for agents, problems, network, governance and institution when forming an NO. In sum, the following scenario initialize the functioning of the NO paradigm. Agents live on a network of interactions that coordinate their actions. When they first join an NO to work on multiple problem profiles, they share their profiles with others for possible future tasks allocation. Their actions are controlled through the governance of their NO or inherently through institutions where the NO belongs. To this end, we contribute measurements for finding the different values relations among agents as well as their capacities. Then, we introduce four different types of the agents contributions to an NO and show how those contributions lead to corresponding synergistic values among them.

The synergistic values describe deferent levels of compatibilities from one agent to another when performing various actions toward their organizational goal. Even though synergy has been tackled in many literature up to date as we will detail in the next section, we focus on measuring values of synergies resulted from agents' contributions without predefined obligations. Such unexpected contributions is considered to be benevolences which, in result, leads to the formation of synergistic collaboration. Benevolence appears when agents actively pursue mutual tasks. When benevolences are aligned, synergy arrises. This paper illustrates how aligned benevolences can be used to quantify synergy.

In summery, the main contributions of this paper are to provide different measurements for the following:

- Relations based on implicit as well as explicit links,
- Four different types of benevolence from agents' relations and capacities,
- The correspondent synergistic values of each type of benevolence, and
- The synergistic values in a simplified scenario using a multiplayer online game.

The paper will be organized as follows: Section 2 will discuss related research about synergy and how it compares to our work. We identify, in Section 3, two main parameters that directly contribute to our measurements of different synergistic values. This section extends to measure agents' links and how do they contribute to the different values of their relations followed by a measurement of agents' capacities. Section 4 will provide four different types of agents' contributions (i.e., benevolences) inside an NO and a way to extract synergies from each one of them. Section 5 will discuss a sample case study using a video game that simulate a possible form of an NO. We will conclude with a brief discussion about the case study in Section 6.

Related work

Previous studies that focused on the traditional form of organizations were constructed as a homologous structure formed from continuous cooperative interactions among different organizational entities (Borgatti and Foster 2003). In order to address the frequently changing social and economic landscape they operate on, network as part of the organizational structure was introduced. The wide use of such an inter-organizational structure of NO is relatively neutral and applicable to many real world applications (van Alstyne 1997). This strengthens the social communication of an NO to access critical resources with other NOs on the network (Gulati and Gargiulo 1999; Ekbia and Kling 2005) as well as to agilely adapt to environmental changes (Hovorka and Larsen 2006). Such properties may lead to a plastic transformation in the intra-structure of an NO in order to cope with outside social and information demands which, in result, influences its agents behaviors (Sussman and Siegal 2003; Alqithami and Hexmoor 2014b). The evolution of an NO overtime consequently leads to numerous internal network effects that agents modeling of organizations falls short in exploring them.

Synergy, as one possible effect of the intra-organizational network, increases agents' efficiencies at different tasks by allowing an efficient collaboration within an environment. Several recent works have demonstrated the use of synergy in forming a coalition (Voice, Ramchurn, and Jennings 2012), avoiding conflict in planning (Cox and Durfee 2003), or finding an optimal team (Liemhetcharat and Veloso 2014; Parker et al. 2012). In sum, the traditional application of synergies among agents produces twofold benefits: (1) improving quality or division of tasks in teaming, and (2) improving utilities by having group power in coalitions. However, the use of synergy in an NO allows agents to confront the environment, maintain homeostasis, adapt, react, handle common problems for a longer term that is more robust than the previous benefits. Benefits are derived from increased affinities among agents through repeated positive interactions among them. Our study of intra-organizations seeks to establish synergy as interconnections rather than as analysis of utilities within coalitions.

In a recent work (Liemhetcharat and Veloso 2014), the authors examined synergy among agents using a social network framework. They built a task-based synergy graph to create an ad hoc team that is efficient in comparison to others without interfering with existing team structure. The value of synergy between two agents is determined through both agents' normally distributed capabilities as well as the compatibility function of the shortest distance between them. This approach is useful in many application that takes advantage from synergy to increase its efficiency (e.g., optimal team formation). In this paper, we extend the view of synergy to include different measures of agents implicit and explicit affinities despite distances for the lack of their determinations in scenarios similar to an NO as well as a new perspective of agents' capacities rather than current contributions. We believe that there are implicit synergistic values in every collaborative environment, such as an NO, that are perceived differently to improve the outcome. This paper focuses on determining the synergistic values resulted from the benevolent contributions of individual agents toward the continuation of their community.

The rich literature on synergy has provided our approach with quite valuable components. The deployment of those parameters into this work in order to efficiently measure and exploit synergy in an NO results in several benefits. This is because our interest is on measuring the value of synergy in an emergent open environment without considering obligations in the agents' contributions, which has set it apart from traditional prior techniques.

Parameters of Synergy

In any organization of networked agents, such as an NO, there is a level of inter-agent compatibility in which the agents can work together effectively. As long as there are continual interactions between agents inside the NO, we describe these levels of compatibilities as synergy (Liemhetcharat and Veloso 2014). When a part of these interactions is not active, their synergies will be reevaluated and they may affect the total synergy of their corresponding NO. There exists synergy for each pair of agent as well as a synergy for the local and global network in the context of each task that has been assigned. The synergy will change over time due to the scale of dynamism in an NO while performing multiple tasks.

Agents entering an NO and interacting with whom they have not previous interactions are initializing their synergistic value with a constant of a *Null*; then, it is derived from her relationships with others as well as her capacity to overcome certain problems. In this section, we will first propose a measurement of relations from continual interactions. Then, we go to describe a possible quantification of an agent's capacity before we attend to finding the value of synergy in the follow up section.

Before we can dive in detail, a measurement of synergy are based on a task-based graph inherited from the NO graph. An NO is modeled as a directed graph of $\{\mathcal{N}, R_{elation}\}$, where $\mathcal{N}$ is the set of agents in an NO, and $R_{elation} \subseteq \mathcal{N} \times \mathcal{N}$ is the set of directed relations between agents. Each goal will be assigned to a subgroup of $N \subseteq \mathcal{N}$. The vertices in the graph will show the corresponding capacities for agents throughout the paper.

Relations Measure

In order for agents to tackle different problems for the continuation of their NO, they form a subgroup that best fits for a given problem. Even though their relations have a huge impact on the formation as well as the coordination in this world, subgroup formation as well as task or problem allocation is outside the scope of this paper. We focus on measuring network of relations for subsequent determinations of different synergistic values that each agent accumulates when interacting with others. The initial values of relations are provided by every agent when she first joins an NO based on her history of previous interactions; otherwise, an agent relations will be determined through her implicit links as we will describe later this section. Those relations and their values are not static and agents are able to create, diminish, or improve each one of them depending on their current actions and interactions.

An NO performs many activities over time. For every action, there exists a problem-profile that define a goal $G_j \in \{G\}$—set of goals. Each goal will be distributed into a set of tasks, such that $G_j \rightarrow \{\Theta\} = \langle \theta_1, \dots, \theta_m \rangle$, for possible assignments to agents. The coordination as well as control of those tasks are determined by the NO and is beyond the limits of this paper. We benefit from the dynamic interactions among agents while achieving multiple tasks in order to update the current values of relations. Those values of relations ebb and flow depending on the nature of interactions over every given task; therefore, we model relations in a task-based scenario to describe the continual changes in inter-agent connections and to help in updating relations throughout repeated task assignment.

The strength of connections For every task assigned, agents form a task-based graph upon the initial relations to prescribe a plan. Agents are able to strengthen an edge through successive interactions over an existing but weak edge. Interactions are commonly observed over two types of affinities, where (a) *explicit affinities* become evident through interactions over an existing relation (i.e., it is observed when two or more agents have interactions with whom they have a previous experience over an existing edge in the graph), and (b) *implicit affinities* allow any other possible interactions among agents without previously modeled relations. These interactions emerge from closure property of relations and may help in forming new edges when updating relations.

For the current values of relations to be updated and a new graph to be formed, the assignment of current task must be completed. For that, we update the graph only for every time a new task is assigned. We describe existing relations as explicit links; otherwise, they will be considered as implicit. Values of links are proportional to the frequency of interactions over them. For agent $i \in N$, the value on an explicit edge, $\mathcal{L}$, is the frequency of interactions that agent i has had with all its explicitly linked neighbors. This value is computed by adding positive and negative interactions to arrive at an overall value of these interactions.

Lets restate that the initial value of any explicit link ($\mathcal{L}$) is the value inherited from the relations. For every new assignment of task, an explicit link between two agents $i, i' \in N$ is updated by adding its current value with the sum of all interactions over that link throughout the time interval (i.e., $\Delta t = t_2 - t_1$). Interactions represent the positive and negative values of social flow as well as abundance of communication over a common subtask (θ^s_m). This is stated in Equation 1.

$$\mathcal{L}_i^{i'}(\theta^s_m, t_2) = \mathcal{L}_i^{i'}(\theta^s_m, t_1) + \sum_{r \in \Delta t} I^{i,i'}_{nteractions}(\theta^s_m, t_r) \quad (1)$$

where $\theta^s_m \subseteq \theta_m \in \{\Theta\}$, $\forall i \neq i' \in N$, and t for time.

Implicit links are traditionally observed through triadic closure theory (Granovetter 1982). Triadic closure, in short, asserts that for each three agents i, i' and i'' where two explicit affinities exist in term that link $i \leftrightarrow i'$ and $i' \leftrightarrow i''$, there should exist an implicit affinity that links $i \leftrightarrow i''$. So that, the value of the third implicit link $\mathcal{L}_i^{i''}$ in a triadic closure will be approximated in Equation 2.

$$\mathcal{L'}_i^{i''}(\theta_m) \approx \frac{\mathcal{L}_i^{i'}(\theta^s_m) + \mathcal{L}_{i'}^{i''}(\theta^s_m)}{|R^{i,i'}_{elation}(\theta_m) + R^{i',i''}_{elation}(\theta_m)|^2} \quad (2)$$

where $\theta^s_m \subseteq \theta_m \in \{\Theta\}$ and $\forall i \neq i' \neq i'' \in N$

We are considering the formation of implicit links through explicit links only (i.e., there must be an explicit path from the source node to target node in order for an implicit link to exist). The traversal in the path of unrepeated explicit links between i and i' will consider the maximum volume despite distances. An extension of the closure envisioned in (2), where there existed two disjoint (i.e., nonconsecutive) links with explicit affinities or possible undefined links in between, is determined through Equation 3.

$$\mathcal{L'}_i^{i'}(\theta^s_m) \approx \frac{1}{|\sum_{i,i'} R^{i,i'}_{elation}(\theta_m)|^2} \cdot \sum_{i,i'} \mathcal{L}_i^{i'}(\theta^s_m) \quad (3)$$

where $\theta_m^s \subseteq \theta_m \in \{\Theta\}$, and $\forall i \neq i' \in N$.

Agents interactions are instrumental in forming new implicit links and in an updating the values of existing explicit ones. During a task completion, it is possible for the frequently used implicit relations to gain a sense of actualization; thereby, the implicit relations will be treated the same as explicit ones. Next, we model relations considering those measurements of explicit as well as implicit links.

Deriving relations from links As stated earlier, the initial values of relations are provided by the agents and are used in forming a task-based socio graph. We mapped those relations to explicit links in a task-based graph in order to capture current interactions as well as to allow possible measures of implicit links. By the time a new task is going to be assigned, an NO updates agents' relations over all tasks based on the new values of links . When a relation from an implicit link ($\mathcal{L}'$) reaches a threshold value of τ that has been specified previously by an NO, it will be treated as an explicit one and an agent is able to explicitly form a relation over it. It is possible for those relations to have a value of positive, negative, or mutual for non-existing or possible unprejudiced relations. Agents will update their profiles as well using those new relations values for a later possible assignment. Equation 4 updates the initial value of relation between every pair of agents by considering the most repeated value over an explicit or an implicit link at a given subtask.

$$R_{elation}^{i \to i'}(\theta_m) = \underset{s}{\text{mode}}\left(\mathcal{L}_i^{i'}(\theta_m^s) + \mathcal{L}'{}_i^{i'}(\theta_m^s)\right) \tag{4}$$

where $\forall\ i \neq i' \in N$ and $\forall\ \theta_m^s \subseteq \theta_m \in \{\Theta\}$.

At this point, we have presented a methodology for relations measurement among agents from interactions. Those relations will also be applied the values in the general graph on the NO by the goal completion, which will allow future possible assignment to benefit from current updates relations. Relations is the main parameter in finding the synergistic values among agents; however, it is not the only one. Agents' capacities are also an important factor in determining synergy, as we are going to detail next.

Capacity Measure

An evaluation of an agent's capacity is an important factor that should be determined by the time an agent joins an NO (e.g., a task allocation to an ineligible agent may not result in a task completion). Those capacities are dynamic and rapidly changing from one task to another. It is a combination of her (1) capabilities for the ability to achieve different tasks, (2) willingness to perform certain actions based on her preferences, and (3) availability for her readiness to participate. Equation 5 shows a possible measurement for an agent i's capacity when achieving a certain task θ_m.

$$C_{apacity}^{i}(\theta_m) = \Big(\mathsf{capability}_i(\theta_m) + \mathsf{willingness}_i(\theta_m)\Big) \times \mathsf{availability}_i(\theta_m) \tag{5}$$

where $\theta_m \in \{\Theta\}$ and $\forall\ i \in N$

For the rapid changes in the agent's capacity, an agent will not be able to preserve them for a future use. They must be updated instantaneously every time a new task is assigned. To this end, the modeling of agents' relations as well as their capacities have allowed us to measure their benevolences from one to another in an NO, which may lead to synergy.

Agents Benevolence

The existence of agents in a weighted graph of relations allow them to contribute to one another for the benefit of their NO. Since agents are under no obligation to perform prescribed tasks, agents contributions are considered benevolences. Thus, an agent benevolence is the total values of her current contributions to others. Since such benevolences are directed from one agent to another in any given task, we model benevolences in a task-based directional graph where the nodes are agents and edges are the different values of their relations. There are different possibilities for modeling benevolence in an NO. We only model four most common types and exploit them to expose the possible values of synergies in an NO.

Directed Benevolence

In a directed graph, a directed relation between two agents (i, i') contributes to the value of their synergy through benevolence. The directed benevolence describe an agent direct contributions to another agent. It is affected by the capacity of the agent offering benevolences and the current relation between the giver and the receiver of benevolence. Thus, the value of benevolence is extracted from Equation 6.

$$B_{enevolence}^{i \to i'}(\theta_m) = R_{elation}^{i \to i'}(\theta_m) \cdot C_{apacity}^{i}(\theta_m) \tag{6}$$

where $\forall i \neq i' \in N$ and $\theta_m \in \{\Theta\}$.

In this case, the value of synergy in between two agents (i, i') is proportional to the value of benevolence between them; however, the opposite may not always hold. Synergy is a reciprocal value between a pair of agents, i and i', that sums the given and received benevolences between them in turn. This s shown in Equation 7.

$$S_{ynergy}^{i,i'}(\theta_m) = B_{enevolence}^{i \to i'}(\theta_m) + B_{enevolence}^{i' \to i}(\theta_m) \tag{7}$$

where $\forall i \neq i' \in N$ and $\theta_m \in \{\Theta\}$.

The value of synergy is not applicable here unless there are two opposite sides of directed benevolences. In a case where the reciprocal does not hold, the few next types of measurement might be applied; otherwise, it will be ignored. This type only covers directed contributions from one agent to anther when performing a certain task. Nevertheless, contributions that is aimed toward the benefit of the group whether diffused for all of them or toward a mutual goal they share are considered general benevolences that we will detail next.

General Benevolence

It describes the total contributions of an agent toward the benefit of the group without expecting anything in return.

This is also observed in the contribution of one agent to the global goal. Since an agent's contributions is not enough as well as not certain for the goal completion, it is considered benevolence toward a global good. Unlike the previous type of directed benevolences, this type does not consider specific benevolences and only the ones that benefit the whole group are considered. Despite the fact that explicit links ($\mathcal{L}$) may not be formed in this case, an agent is implicitly forming a relation (i.e., through $\mathcal{L}'_{i \to g}$) when she is contributing for a mutual task (θ_m) in a subgroup ($g \subseteq N$), where every agent in this subgroup are contributing to the task (θ_m). For that, the measurement of this type is through Equation 8.

$$\begin{aligned} GB^{i \to g}_{enevolence}(\theta_m) &= B^{i}_{enevolence}(\theta_m) \\ &= C^{i}_{apacity}(\theta_m) \cdot \sum_{i' \in g} R^{i \to i'}_{elation}(\theta_m) \end{aligned} \tag{8}$$

where $\forall i \neq i' \in g \subseteq N$ and $\theta_m \in \{\Theta\}$.

The value of relations in Equation 8 is a task-based to describe the possible current value of interactions of possible existing implicit links with previous value of the link. It is worth mentioning that an agent is contributing benevolences to others when performing actions on their behalf. For that, her general benevolence is the value of her capacity multiplied with her current relations with others inside the group (g).

Synergy can be exhibited here when the value of contributions to the general benevolence of one agent is affected by another agent actions or contributions. The existence of synergy may improve or diminish the outcome of an agent. I.e., when an agent is supported by her teammates in order to perform an action, the contribution of her action result in a higher impact than what is expected when the action is performed individually. Equation 9 shows a possible way to measure such synergy.

$$S^{g}_{ynergy}(\theta_m) = \sum_{\forall i \in g} GB^{i \to g}_{enevolence}(\theta_m) \tag{9}$$

where $\theta_m \in \{\Theta\}$ and $i \in g \subseteq N$.

Synergy here is proportional to an agent's general benevolences to others when contributing on their behalf toward task completion. This type focuses on agents who contribute to the goal on behalf of others; however, when an agent helps another agent for a goal completion without participating directly towards it, it is considered complementary benevolence as detailed next.

Complementary Benevolence

In some cases, agents in an NO do not directly contribute to the main goal; however, they participate by helping others achieve that goal on behalf of them. Their contributions, in most cases, are necessary for a group functioning, and the lack of it may lead to a complete shutdown. Since their benevolences are not directly toward the mutual goal, it cannot be categorized as general benevolence, as described earlier. They are complementing the benevolences of others toward a mutual task. In this case, undirected contribution may result in complementary benevolence when those contributions are aimed to further helps in achieving the global goal. Such benevolence is directed from one agent to another, and it may not intentionally be for the purpose to receive another benevolence. Equation 10 states the benevolent value resulted from this type, where the brackets, $\big[\big|$, represent a condition of follow up action. The condition of an agent to have a subsequent mutual and positive action must hold in this case or such contributions will result in different classification that is not complimentary benevolent.

$$ComB^{i \to i'}_{enevolence}(\theta_m) = \big[\big|\ B^{i \to i'}_{enevolence}(\theta_m)\ \big|\big] \tag{10}$$

where $\forall i \neq i' \in N$, $\theta_m \in \{\Theta\}$ and $\big[\big|$ is the subsequent condition for i'.

Since the aim of this type of benevolence is to achieve the goal, conditional directed benevolences is not the only parameter that contribute to the value of synergy. The general contribution of the receiver agent (i') in conditional benevolences should also be included when measuring the total value of synergy. For that, synergy in this type is an extension of Equation 8 and can be measured through Equation 11.

$$\begin{aligned} S^{i,i'}_{ynergy}(\theta_m) =& \big[\big|\ B^{i \to i'}_{enevolence}(\theta_m)\ \big|\big] \\ &+ GB^{i' \to g}_{enevolence}(\theta_m) \end{aligned} \tag{11}$$

where $\forall i \neq i' \in N$, $\big[\big|$ is the subsequent condition for i' and $\theta_m \in \{\Theta\}$.

Complimentary benevolence is directed from one agent to another; however, the synergistic value generated from it are directed from one agent toward the group. An example of such scenario is the fundraising campaigns for disaster relief. An extension of this case to include a diffusion of complimentary benevolence is discussed next.

General Complementary Benevolence

The final type worth mentioning is to observe benevolences in an NO when agents contribute to other tasks in parallel with the main goal that they aim to achieve. It is also observed when agents adopt different roles toward the completion of a mutual goal. The diffusion of this benevolence is not directed and this has set it apart from the previous model. The general complementary benevolence present the complete values of ones contribution to others that does not directly result in improvement of their outcome. Equation 12 states a possible way of measuring this type.

$$GComB^{i \to g}_{enevolence}(\theta_m) = \big[\big|\ GB^{i \to g}_{enevolence}(\theta_m)\ \big|\big] \tag{12}$$

$\forall i \neq i' \in N$, $\big[\big|$ is the subsequent condition for i' and $\theta_m \in \{\Theta\}$.

The condition here might not hold in most cases. For that, benevolences that fail to meet this requirement are categorized as general benevolence unless this condition is met. The synergistic value of this type will be a combination of the giver current benevolence as well as the all possible benevolences that the receiver agents generally provide to their group. Equation 13 present a way to measure synergy in this type.

$$S^{g}_{ynergy}(\theta_m) = \Big[| \sum_{g} GB^{i \to g}_{enevolence}(\theta_m) \; | \Big] + GB^{g}_{enevolence}(\theta_m) \tag{13}$$

where $g \subseteq N$, $\theta_m \in \{\Theta\}$, and [| is the subsequent condition $\forall i \in g$.

This describes the synergy of the group at a specific task from the diffusion of benevolences complementarily. The condition of the general benevolence must hold in order for synergy to exist. The value of the general benevolences that every agent proposes toward her group is also included in the value of synergy because it states the value resulted when the condition hold.

To this end, we have shown four possible types of the existence of benevolence in a NO as well as measurements of the corresponding synergy to each one of them. The proposed types are not exhaustive and there is a huge possibility for the existence of benevolence in other forms that are not foreseen at the moment. Next section demonstrates the use of those measurements in an empirical case study of a video game.

Case study

It has been a challenge to find an open MAS that best fits the specifications of an NO. Therefore, for the sake of simplicity, we exemplify the previous proposed approach using an ad hoc multiplayer video game that depict a virtual NO, called "*FinalFantasy*[1]". We specifically focus in this game on the scenario where multiplayers work toward a common goal (e.g., destroying the *Titan*). For this goal to be accomplished, the game undergoes multiple phases that we describe as tasks (i.e., $\{\Theta\} \to G_j$). Subtasks may sometimes exist to best describe the contributions that agents did toward the organizational goal. Throughout the assignment of this goal, we observed and tracked 8 human guided players with different roles. We were able to measure several parameters before the start of the game given a set of agents' profiles (e.g., an agent's capability is a combination of her strength, dexterity, vitality, intelligence, mind, and piety.) Several other parameter are given random values that best describe their role in the game (e.g., importance and availability). Table 1 summarizes the role and initial values for each player.

Table 1: Players and their initial values

Strength	Dexterity	Vitality	Intelligence	Mind	Piety	Role	Capability	Capacity[2]
112	214	438	210	576	439	*White Mage*	2199	660
442	193	673	119	201	171	*Paladin*	1918	383.8
446	191	594	83	111	88	*Warrior*	1596	0
111	212	418	215	565	362	*White Mage*	2098	1049.5
630	204	496	88	130	151	*Dragoon*	1787	1609.2
318	533	411	134	151	129	*Ninja*	1810	1629.9
88	203	399	571	154	244	*Black Mage*	2230	0
91	204	464	632	150	242	*Black Mage*	2415	1691.2

[1] http://na.finalfantasyxiv.com/

In Table 1, the availability of a player to contribute to the goal is set to "0" when she exits the game (i.e., dies) before showing any type of benevolence that can result in synergy. Thus, their availabilities have directly affected their capacities when applying Equation 5. Agents of the game are required to perform different tasks in order for the complete goal to be achieved. Luckily, we were able to observe the four different types of benevolences that we introduced in the previous section. Next, we will examine those four types in order to describe synergy throughout the game.

Directed Benevolence

This type occurs in between two agents, e.g., agent i and agent i'. When such a type of benevolence is mutual, i.e., agent i is giving and receiving benevolence from agent i', then we describe the resulted value as synergy. In the game, we examine this type in the case that one agent (i) is in jail and others try to free her before the allowed time elapses and she is forced to exit the game. Agents will be prisoned randomly and might be in jail multiple times during one game. When the jailed agent (i) is freed and another agent (i') who was trying to free her is in jail instead, agent i will try to benevolently contribute back to free agent i' from jail, which in result produces synergy between them.

We examined the behavior of those agents to help in freeing each other from jail. We have collected all the possibilities of an agent being in jail throughout the game. When the pay back is received, synergy is measured. Table 2 shows a preview of the process of achieving one task (θ_m) for freeing a player from jail. This task is divided into several subtasks (i.e., $\langle \theta^1_m, \ldots, \theta^s_m \rangle$) to describe every time each player happen to be in jail.

Table 2: Synergy from Directed Benevolences

Player Role	θ_m	Capacity	Relation	Benevolence
Dragoon	θ^1_m	7.38349244	1.892266191	97.80073179
	θ^2_m	7.38349244	1.991280136	44.1078055
	θ^4_m	7.38349244	1.792361199	66.16942681
	θ^5_m	7.38349244	2.148157052	79.30450678
Ninja	θ^3_m	7.396273942	2.142736468	63.39306361
	θ^6_m	7.396273942	1.844465082	68.21084513
			Synergistic value	418.9863796

The case of freeing one player from jail is set to be one task (θ_m). This task is divided into different subtasks $\sum_s \theta^s_m \equiv \theta_m$, where every subtask describe one scenario of a player being in jail. Table 2 summarizes the process of computing benevolences between two agents at each subtask, where all the contributions provided from one agent to another at each subtask are accumulated as one benevolence at that specific subtask. It is possible for one player to contribute more benevolence than another (i.e., free someone from jail more often than another). Since the whole case is a task based, it will not be an issue when measuring benevolences (i.e., the contributions of an agent at different subtasks leads to her contributions to the whole task.

[2] Capacity, in this scenario, will numerically be scaled down using the natural logarithm throughout this paper.

General benevolence

This has been observed in the game when a player contributes to the main goal, which is wining the game. A player is expected to be generally benevolent to the group depending on her role in the game, e.g., fighting the *Titan* or diffusion of a cure. We tracked the behaviors of one player, a *Paladin*-introduced in Table 1, and summed up all of her contributions to fighting *Titan* in order to calculate the value of her general benevolence. Table 3 present different tasks where this agent has contributed and how much of those contributions have lead to synergy.

Table 3: Synergy from General Benevolences

θ_m	Relation	Benevolence
θ_m^1	2.604509339	118.1336598
θ_m^2	2.310856624	104.8143488
θ_m^3	2.56034488	135.4855561
θ_m^4	2.352412823	124.4824328
θ_m^5	2.641950614	139.80388
θ_m^6	2.419932318	164.642601
θ_m^7	2.515320951	152.1177471
	Synergy	939.4802257

Subtasks, stated in Table 3, are the different phases for the completion of the task (i.e., the *Titan* goes through different phases before it can be killed and every phase has its own properties and power.) The general benevolences over a set of subtask are summed up to result in a synergistic value that the *Paladan* provided to her group. We have considered this scenario as a task based even though it is the main purpose of the game because the goal of winning the game is not only focused on achieving tasks but also on the group synergy when working together. Although the synergistic measure of the general benevolence stated in Equation 9 includes all the contributions agents provide at a given task, we simply focus on the most common contributor throughout a task completion. The role of the *Paladan* and the *Warrier* is to fight directly which mostly benefits the general group; however, the *Warrier* failed to continue in the game for that the *Paladan* was left alone.

Complementary benevolence

In the game, this type of benevolence describe the direct contributions that one player perform for another for the purpose to result in subsequent other actions that may benefit her in return. It also includes the case where players complement the actions of each others (e.g., possibly using a mutual strategy for a better outcome.) Therefore, we exemplify this approach with the scenario of a "*Black Mage*" freeing someone from jail in order for them to contribute to the common goal (i.e., the player involvement in the case presented in section 5.1 between *Dragoon* and *Ninja*). Table 4 presents the different values of complementary benevolences one agent performed for another.

The conditional benevolence, presented in Table 4, is provided by the *Black Mage* for freeing the *Ninja* from jail. At this task θ_m, the *Ninja* is contributing directed benevolences correspondingly to the *Dragoon*. Synergy represents what has been offered with the use of it at different specific stages

Table 4: Synergy from Complementary Benevolences

θ_m	Relation	$[\|Ben\|]$	$Ben^{i'}$	Synergy
θ_m^3	2.108982587	31.3529518	141.9085373	173.2614891
θ_m^6	2.656194598	39.48801745	145.4739336	184.961951

that can be added up to a value of 358.2234401 at a specific task of freeing someone from jail.

General complementary benevolence This type of benevolence describes agents' contributions to other tasks in parallel with the main goal that they aim to achieve. It may not directly affect their actions nor the output of a mutual task. Thus, the general complementary benevolence is the complete values of ones contribution to others that does not directly result in improvement of the outcome.

There exists multiple possibilities for observing this type of benevolence in the game. One of them is when the *White Mage* changes her role from healing to fighting instead for the limitations of current contributions. Table 5 summarizes the contributions that the *White Mage* did on behalf of others that she is not expected to conduct.

Table 5: Synergy from the General Complementary Benevolence

θ_m	Capacity	Relation	[| GBen |]	GBen^g	Synergy
θ_m^1	6.956069139	1.804256095	12.55053014	118.1336598	130.6841899
θ_m^2	6.956069139	1.823436331	12.68394919	104.8143488	117.498298

In Table 5, we focused on the *White Mage* contribution to the common goal. The conditional general contributions are toward a shared action (i.e., the *Titan*) at a specific subtask. The general benevolence of the group here is only from the *Paladan* discussed in previous section because she is the only one contributing at that specific subtask.

Those measurement of synergistic values are not exhaustive and does not show all the possible values of synergy in the game. Other scenarios are dismissed in this paper; however, many of them may follow the same procedure to find the synergistic value.

In a game setting where players take individual actions toward a common goal, there can be several interaction patterns through which each player's actions will complement actions of others. Deliberate use of a complementary action pattern by a player constitutes its synergy with the group. Of course, it is not readily possible to ascertain player intent in selecting a synergistic action pattern. However, we can associate the rate of success in the game with each interaction pattern. We can then infer existence and a measured value of synergy with such pairings. This type of emergent synergy heavily relies on the recognition and use of opportunity for cooperation and player action that are beneficent to others.

Opportunity for cooperation appears over time but once again not readily quantifiable. Fortuitous interaction patterns lead to gains in the game and observables are limited to interactions and pursuant gains. By examining spikes in gain we seek preceding interactions. The amount of synergy inherent in each spike is proportional to the amount of gain. However, the degree of each opportunity and seizure of it will likely remain un-quantified. We envision games with large time scales, it might be possible to measure opportunity windows and action patterns that produce synergy. An example of such a long duration game setting is world politics.

Conclusion

We have considered a paradigm for network organization (NO) that best model organizations dwelling on socially connected networks. An NO can be a small team of two or more agents working on a common, quick goal that is possibly faster than human perceptual threshold (e.g., aerial coordination at high speeds) or a large collection of agents made up of thousands of people (i.e., possibly swarms or plagues) working on long term objectives that is possibly beyond a single human's cognitive capacity (e.g., detecting climate change). NO replicates many properties and features of virtual working groups. A specific salient phenomenon is how working together in networks affects their individuals as well as collective productivities. A tightly knit group working more effectively by benefiting from network side effects. Those effects include synergy, social capital, externalities, influence, etc.

Synergy is a type of network effect featured in an NO. It can be found at various levels of mutually beneficial group of work. It is responsible for enhanced collaborative outcome of an organization. By and large, we aim to model synergy from agents interactions. The measurements of finding synergy are applicable to many real world as well as artificial NOs as we have shown through an example that mimics real world NOs. Benevolence is a very common phenomenon in many setting including in network organizations. It is very intuitive to understand synergy through the lens of benevolence. We have made strides in quantifying synergy using benevolence; however, there are many natural forms of synergy that rely on benevolence and beyond. This is fertile research topic as it captures naturally occurring positive interactions in complex network setting. We call to action further elaboration on serendipitous synergy as well as other network effects that remain to be explored in the future.

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