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T-DepExp: Simulating Transitive Dependence Based Coalition Formation

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ABSTRACT

In this paper, we introduce T-DepExp system to simulate the transitive dependence based coalition formation (CF). It is a multi-agent based simulation (MABS) tool that aims to enhance cooperation between agents through transitive dependence. Previously, the transitive dependence was introduced by An and his colleagues for expressing the indirect dependence between agents in their cooperation. However, it did not receive much attention. Although it has a few problems need to be addressed, we try to propose our own mechanism to increase the efficiency of the transitive dependence based CF. To simulate MAS dependence relationship, we have included two fundamental dependence relationships in this MABS tool, which are AND-Dependence and OR-Dependence. In addition, the architecture of the T-DepExp system is presented and discussed. It allows possible integration of other features such as budget mechanism and trust model. Subsequently, hypothesis for the experiments and experimental setup are explained. The overall system will be demonstrated for its functionality and the experimental results will also be discussed.

Keywords: T-DepExp system, coalition formation, multi-agent based simulation, dependence relationship

INTRODUCTION

Multi-agent based simulations (MABS) have become one of the popular tools that help computer scientists to simulate multi-agent systems (MAS) without developing the actual system for simulating certain features. It aims to enhance the performance of MAS in terms of space complexity, time complexity and computational complexity. By defining the performance of MAS, the cooperation between autonomous agents in the society for expressing (Castelfranchi, 1998; Sichman, Conte, Demazeau, & Castelfranchi, 1998) the need of depending on others. This phenomenon is known as heterogeneous need among autonomous problem solvers in the society that leads to cooperation between agents. The cooperation formed between the agents in a group that are goal directed is known as a coalition.

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Coalition is a goal-directed and short-lived organization and framework for agents to perform problem solving in a distributed manner (Sycara, 1998; Wooldridge, 2009). The cooperation between agents in coalition can be instant and dissolved when there is no common goal. Coalition formation (CF) is often viewed as an optimization problem for the cooperation between agents in problem solving. It offers a quick formation of group for tackling the dynamic environment of MAS. However, coalition suffers some of the limitations such as coalition formation is invisible (An, Shen, Miao, & Cheng 2007), where other agents are not aware of it. In order to address this drawback, social reasoning mechanism (Sichman *et al*., 1998; Gaspar & Morgado, 2000; Sichman & Demazeau, 2001) has been implemented to aid agents in identifying the social needs of dynamic coalition formation in a real-world agent environment.

The social reasoning mechanism (SRM) (Sichman *et al*., 1998; Gaspar *et al*., 2000; Sichman *et al*., 2001) has opened its way for forming the dynamic coalition by identifying whom a particular agent is going to depend on and vice versa. In addition, it has introduced several types of dependence relationships such as (1) OR-Dependence, (2) AND-Dependence, and (3) CO-Dependence. One of the most significant developments of SRM is the visualization of the dependence network between agents into dependence graph. It offers researchers an easier modelling of the agents' dependence. Utilizing the dependence graph, we can represent the coalition formation in graph and further investigate the relationship and reason of coalition formation fails. Some researchers (e.g. An, Miao, & Cheng, 2005a; An, Miao, Tang, Li, & Cheng, 2005c; An *et al*., 2007) have also shown a transitive dependence relationship when forming a coalition between agents that can be applied in manufacturing field.

To the authors' knowledge, despite the formalization of transitive dependence, not much research has been done in this field. Furthermore, there is no standard software or tools that support the transitive dependence based coalition formation. To this end, the T-DepExp system has been proposed to simulate the transitive dependence between agents to form coalition. The design of the T-DepExp system is based on the original concept introduced by An and his colleagues (An *et al*., 2005a; An *et al*., 2005c; An *et al*., 2007) and we have introduced the extendibility into the T-DepExp system for future development of mechanism and experiments. The T-DepExp system aims to develop an alternate mechanism for forming transitive dependence based a coalition that encourages the indirect cooperation between agents in problem solving.

The rest of the paper is organized as follows: First, the related work of the T-DepExp system is introduced in Section II. Subsequently in Section III, the concept and architecture of the T-DepExp system are explained for running the experiments on transitive dependence based coalition formation. In Section IV, the experimental setup and results as well as the analysis are presented based on the observation. The conclusion of the T-DepExp system and future works are presented in the last section.

RELATED WORK

The literature review related to the T-DepExp system is presented in this section. It consists of (1) Coalition formation, (2) social reasoning mechanism based coalition, and (3) transitive dependence.

Coalition Formation

Coalition is a type of dynamic organization in MAS which is goal-directed group for agents to form cooperation. It is a short-lived group that is formed and dissolved when it is no longer needed (Horling & Lesser, 2004). Coalition Formation (CF) is often viewed by researchers as an optimization problem of MAS' cooperation. The need for forming coalition is based on the limited capability of the agent itself to achieve the required specific goals. Hence, the agent will depend on other agents to fulfil the required capability to achieve its goals. This phenomenon is known as social needs or dependence theories that are presented in some papers (Castelfranchi, 1998; Sichman *et al*., 1998). An example of the coalition formation is shown in Figure 1.

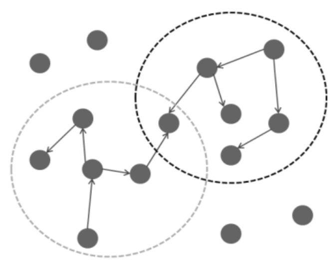

Fig.1: Example of the coalitions in MAS

The dotted circles in Fig.1 represent the coalition boundary, while the bold dots represent agents in the society. One problem of the coalition is that the possibility of overlapping issues occurs during CF, as shown in Fig. 1. This suggests that an agent can join more than one coalition in parallel.

CF is originated from the game theory (Osborne & Rubinstein, 1994) and has been widely studied for its dynamic formation of group. It is also known as coalitional game. Organization such as coalition is suitable for tackling the open multi-agent system (OMAS). OMAS is the MAS societies that have high dynamic elements and they require agents to be hyper-adaptive. There are a few payment configurations developed along with the coalition such as (1) Shapley Value (Shapley, 1953), (2) Kernel (Morton & Michael, 1967), and (3) Core (Klusch & Gerber, 2002). The payment configurations aim to distribute the profit of the coalition to all the agents involved. It may vary depending on the element the payment configuration emphasises on such as fairness, uniqueness, and consistency.

Social Reasoning Mechanism Based Coalition

Social reasoning mechanism (Sichman *et al*., 1998; Gaspar *et al*., 2000; Sichman, *et al*., 2001) (SRM) was developed to assist an agent to reason about other agents in the MAS society. SRM is based on the dependence theory that proposes the social need of an agent and is required to depend on other agents. The SRM relieves the communication flow between agents by identifying them using the social reasoning. This mechanism helps an agent to achieve a given goal by reasoning about other agents in two different social views (Sichman *et al*., 2001): (1) Whom do I depend and (2) Who depends on me. The dependence relationships show the relationship of an agent depending on other agents to achieve its goal using the required capabilities. The dependence relationship formed can be classified into: (1) AND-Dependence, (2) OR-Dependence, and (3) Single-Dependence. The three fundamental dependence relationships in the proposed T-DepExp system are described in Table 1 below:

TABLE 1: Type of the Dependence Relationship

Type of Dependence Relationship	Explanation
OR-Dependence	This relationship indicates that agent has option of choosing agent to cooperate for achieving its goals.
AND-Dependence	This relationship indicates that agent would have to take account all party of agents since all agent are required for achieving the goal.
Single-Dependence	This relationship indicates the agent only has a single option in choosing the partner for achieving its goal.

On the other hands, OR-Dependence, AND-Dependence and Single-Dependence can be expressed in a mathematical form:

- AND-Dependence

$$AND\_Dep(Agt_j,agt_l p_{qk})=\forall ag_k\in G(agt_k)\neg a_{aut}\ (agt_l,g_k\ p_{qk})\wedge\forall i_m(p_{qk})\in I(p_{qk})a_m\in A_n(agt_i,g_k,p_{qk})(\exists!Agt_k\in AG\ |Agt| = \exists agt_l\in Agt_k)basic\_dep(agt_i, agt_l,g_k p_{qk}, a_m)\vee \exists!Agt_k\in Ag_j OR\_dep(agt_i,Ag_k,a_m)\wedge\neg\exists AG_m AG_j\subset AG_m AND\_dep(agt_l,AG_m,g_k,p_{qk}) \quad (1)$$

- OR-Dependence

$$OR\_Dep(agt_J,Agt_j,g_k a_m)=\exists g_k\in G(agt_i)\neg a_{aut}(agt_i,g_k,p_k)\wedge|Agt_j|\wedge\forall Agt_l \in Agt_j\ basic\_dep(agt_i,agt_l,g_k,p_{qk},a_m)\wedge\neg\exists Agt_m Agt_j\subset Agt_m\ OR\_Dep(agt_i,Agt_m,g_k,p_{qk},a_m) \quad (2)$$

- Single-Relationship

$$Single\_dep(agt_i,agt_j,p_{qk},g_k) \equiv \exists g_k\in(agt_i,g_k,p_{qk})\wedge\forall Agt_l\in Agt_j basic\_dep(agt_i,agt_l,p_{qk},a_m)\wedge\exists Agt_m Agt_j, \subset Agt_m OR\_dep(agt_i,Agt_m,g_k, p_{qk},a_m) \quad (3)$$

Other related works of SRM include identifying four structural viewpoints (Boella, Sauro, & Torre, 2004) of an agent in a coalition such as: (1) power view, (2) mind view, (3) coalition view, and (4) dependence view. SRM also has its place in social exchange (Rodrigues & Costa, 2003; Rodrigues, Costa, & Bordini, 2003) that exchanges value introduced to support the social interactions between agents. It is based on the algebra of exchange values that the structural value of storing and manipulating is done by modifying SRM. In addition, we also reviewed the work of Lau, Singh and Tan (2012) on the dependence graph of agents with SRM in our previous works.

Transitive Dependence Relationship

The transitive dependence is an indirect dependence between the agents in the society that is introduced by An and his colleagues (An *et al*., 2005c; An *et al*., 2007). They have shown a possible indirect dependence relationship between agents using SRM.

The transitive dependence is based on the dependence chain that the starting agent (also known as head) will connect to an ending agent of the chain (known as tail) by a series of connected agents sharing the same goal to achieve. Fig.2 shows the example of the transitive dependence relationship based the coalition formed:

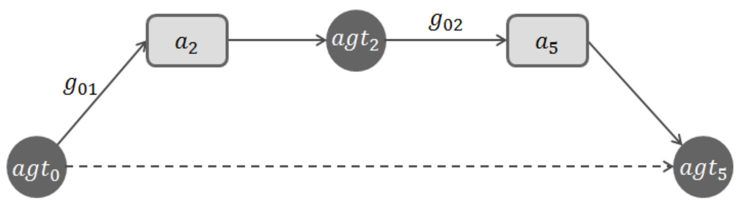

Fig.2: Example of Transitive Dependence

From Fig. 2, the transitive dependence relationship for the agents in the cooperation can be expressed as *dep* = *TDep(agt*$_o$*, agt*$_5$*,depchain)*, where *depchain* = $agt_o \xrightarrow{p_g01,a2} agt_2 \xrightarrow{p_gO_2,a5} agt_6$. Transitive dependence relationship is proven (An *et al*., 2005a; An *et al*., 2007) to encourage agents to help each other regardless of the profits gained from the direct dependence. The main concept behind the transitive dependence is indirect profitable cooperation that will lead to overall profitable cooperation among the agents.

Other related works of transitive dependence include the application of transitive dependence into virtual organization (An, Miao, Shen, Miao, & Cheng, 2005b). This application includes service discovery and partner-searching features using transitive dependence based reasoning. However, the auto-complete knowledge of an agent in the transitive dependence shows an agent has a complete knowledge regarding itself, which is impractical.

T-DEPEXP SYSTEM

In this section, we have proposed the T-DepExp system for simulating the transitive dependence between agents in coalition. The concept of the T-DepExp system is explained in the first sub-section. Subsequently, the system design of the T-DepExp system is presented and explained. The parameters for conducting the experiments are explained in the last sub-section.

Concept of T-DepExp System

T-DepExp system is a MABS software that aims to provide alternate payoff mechanism to CF other than Shapley value, core and kernel. The Shapley value is the most popular payoff mechanism since it offers fair payment to all agents involved in coalition formation. However, the Shapley value (Shapley 1953) has a higher computation complexity since it involves permutation and factorial when calculating payoff (also known as utility) for each agent. The core (Klusch *et al*., 2002) suggests that agents do not need to have unique payoff configurations when forming coalition. However, searching for core optimal coalition structure is computationally difficult. The kernel (Morton *et al*., 1967) introduces stable payment configuration where there is an equilibrium between the agents in the coalition. The main drawback of the kernel is that it cannot guarantee parento optimal condition where all agents are getting equal paid for joining the coalition.

For explanation of the transitive dependence based coalition example, the coalition formed with three agents shown in Fig. 2 is considered. This coalition has a centralized view as we will call agent, agt_o, as a root agent to form coalition and agent agt_5 as the leaf agent where there is no more "potential child" to invite for forming a coalition. Similar concepts are applied in the T-DepExp System as the programme reaches leaf agent and when there is no more child to invite to join the coalition, it is considered that no more coalition will be formed. In the T-DepExp System, however, the coalition of n-size will be tested that wishes to able to handle larger group of agents.

Together with the T-DepExp system, the authors aimed to create an alternate payoff mechanism based on the concept of budgets. The main purposes of designing encourage the cooperation between the agents. Assume that all the agents in the society are applying the sincerity principles, the agent that has higher cost in the society will have a lower chance of involving into coalition formation. Through the development of budget mechanism, the agents will have equal chance of involving into the coalition to earn profits. If the cost is within the budget requirement, the coalition will then be formed, giving the chance to other agents to involve into the coalition.

The T-DepExp system attempts to address the issue of the transitive dependence based coalition which is useful in three-tier systems. It includes the n number of middle-man for forming the cooperation. Most MABS tools available emphasize on direct dependence between agents. The motivation of the T-DepExp System is an attempt to address indirect dependence between the agents. This enables them to have a larger perspective of their cooperation instead of their first-person's view.

The Proposed T-DepExp System Architecture

In this sub-section, the architecture of the T-DepExp Systems is proposed. It shares some common features of the ASIC Model (Boissier & Demazeau, 1994) proposed by Boissier and his colleagues. The fundamental composition of this architecture is the external description of the agents. By introducing the external description, we can address our agent architecture using belief, desire and intention (BDI) architecture (Wooldridge, 2009). The BDI architecture which represents the agents in the MAS society are able to reason, have their own trust towards other entities and goals to achieve. Fig.3 shows the architecture of the T-DepExp system.

The T-DepExp system is constructed with the external mechanism for assisting the agent to make a better decision and give reasoning about the environment and social status. The main focus of the T-DepExp system is simulating the transitive type dependence during CF. Hence, SRM and social evaluation module play an important role here for the agents to analyze their social status.

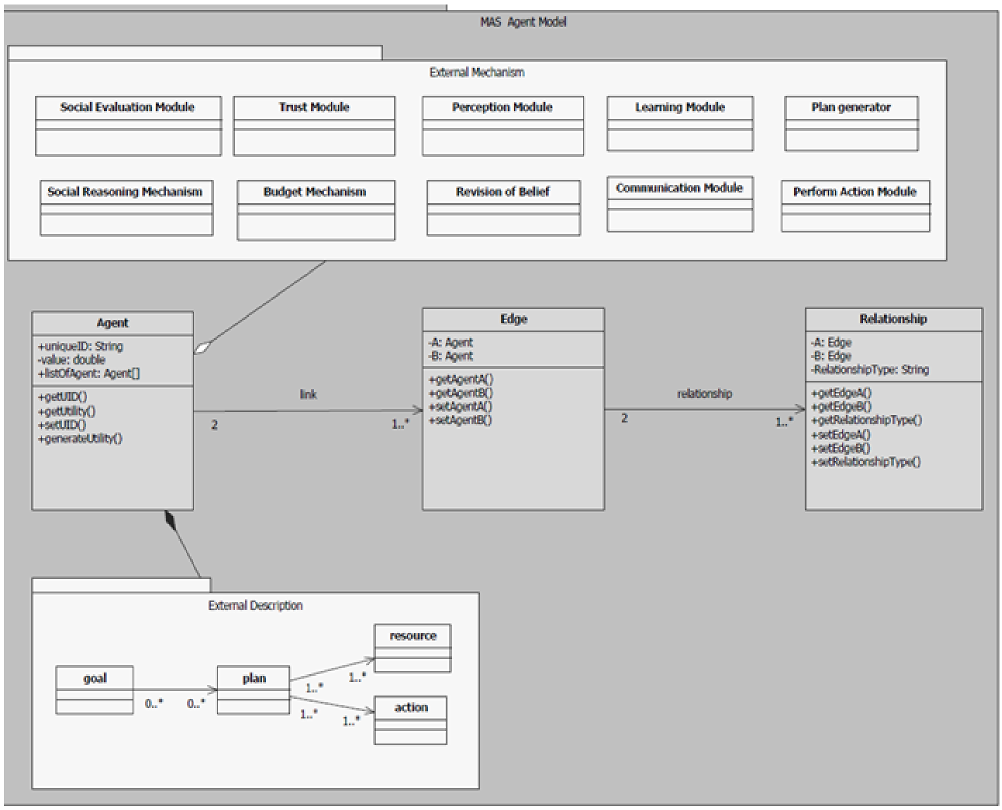

Figure 3: The architecture of the T-DepExp Systems

The T-DepExp system has a robust learning module that learns based on the outcome of their decision. It will learn based on the outcome of the transitive dependence based coalition. The plan generator will generate plan for the agent after the learning module is invoked. Meanwhile, the communication module serves as a medium for the agents to communicate among themselves. The T-DepExp system architecture consists of trust module, where credibility of the agent is given attention here. It is to mitigate any malicious agent to cheat on the agents' profit. Nonetheless, it is not guaranteed that the agent will avoid the cheating issue completely. Hence, the trust model implemented here is using the reputation and confidence (Ramchurn, Sierra, Godó, & Jennings, 2003). The Reputation model suggests that the agent will gain trust if friends of an ally have received positive feedbacks from other agents.

The T-DepExp systems was developed using JAVA programming language. It offers cross-platform compatibility to execute the programme. Hence, it has become the choice of the programming language. It was designed with object-oriented concept in mind incorporate iterative waterfall model lifecycle. One major focus of this program is the extendibility of the new mechanism implementation. The mechanism that uses external description will run well with the T-DepExp system.

Parameters Input and Hypothesis

The T-DepExp System requires certain input for generating the outcome of CF. The society of MAS is randomized based on the setting for getting un-bias results. For the experimental setup in this study, Table 2 depicts the parameters to be input for running the simulation of transitive dependence based CF:

TABLE 2: Parameters for Inputing into Simulations

Parameters	Descriptions
n	Number of agents in the society
P_a	Probability / Ratio of agent having an action to achieve the goal assigned.
P_{and}	AND Ratio of the relationship occurred when requiring the action/resource from other agents.
P_{or}	OR Ratio of the relationship occurred when requiring the action/resource from other agents.
v	Budget value that are allocated for coalition formation.
i	The payout for accepting the coalition invitation
i_{max}	The maximum payout for agent to propose for the value per each action.
i_{min}	The minimum payout for agent to propose for the value per each action.

The T-DepExp system emphasizes on the searching ideal amount of budget for an agent to form transitive dependence coalition. Below are the hypotheses for the experiments conducted with the T-DepExp System to adapt budget mechanism and calculate a suitable budget for forming a feasible coalition.

- Hypothesis 1: Optimal amount of budget encourage the cooperation of the agent to form coalition (until an optimal budget is reached).

The amount of budget serves as a threshold to the size of coalition that an agent wants to perform. If the amount of budget is optimal, the coalition can be formed regardless of the number of agents in the coalition. It ensures that every agent in the coalition will obtain profit through the cooperation with other agents. Hence, it is believed that the optimal amount of budget will encourage the cooperation of agents in the transitive dependence based coalition.

- Hypothesis 2: Bad planning (relationship ratio increase) will decrease cooperation between agents.

The incremental of the relationship ratio suggests the dependence relationship between agents in the coalition increases. It increases the computational time to traverse through the dependence relationship. In addition, the coalition value will increase and tend not to meet the allocated budget for CF. Hence, the rate of the cooperation will go down. Hypothesis 2 is indirectly opposite of Hypothesis 1 for the rate of cooperation. Hence, the incremental of the relationship ratio will decrease the rate of cooperation between the agents.

- Hypothesis 3: Higher OR-Dependence ratio will decrease the computational time of CF in the T-DepExp system.

The ratio of the OR-Dependence will have an impact on the CF computational time. It is believed that a higher ratio of OR-Dependence will yield more alternate choices for agents to choose. This is in contrast with the AND-Dependence ratio, where the agent is not required to consider all the agents in the dependence relationship. Hence, it is assumed that a higher ratio of the OR-Dependence will form the transitive dependence based coalition in a shorter computation time than the AND-Dependence.

EXPERIMENTAL RESULTS

In this section, the experiment of the T-DepExp system is conducted and the analysis of the results is discussed based on the observation. The performance measurement of the experiments is discussed in the first sub-section. Subsequently, the results of the experiments are displayed. Lastly, the last sub-section includes the discussion on the results and observation.

Performance Measurements

For the T-DepExp system, the authors have included their own measurements for the CF in the T-DepExp system. It aims to test the efficiency of the new implementation of the mechanism and algorithm for future upgrades. The performance measure for conducting this experiment is shown in Table 3 below.

TABLE 3: Performance Measurement

Measurements	Descriptions
N_{total}	The number of coalition that is successfully formed per simulation.
B_{total}	The budget in term of utility for forming coalition.
V_c	The value for the coalition formation.
$V_{average}$	The average of the coalition formation for multiple simulations.
R_c	The profit that gained for forming the coalition.

RESULTS

The simulation of the T-DepExp System was conducted using the computer with the specifications of Intel Xeon processor and 16GB RAM. The dataset to be inputted into the simulation were randomly generated during initialization of the simulation. The focus of the simulation was to obtain a suitable budget for supporting budget mechanism in forming transitive based coalition. Also, the cooperation rate between agents was also tested in the simulations of the T-DepExp system. Table 4 shows the results of the simulation.

TABLE 4: Result for Simulating for Agent Size of 10

P_{and} \ P_a	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0.0	29.0	21.4	17.8	29.8	40.8	30.0	7.6	24.6	-	11.0	-	10.2	26.2	-	9.6	11.8	10.4	9.8	-	-
0.1	42.4	9.4	29.2	34.8	17.0	47.4	26.6	31.0	30.6	6.4	11.2	18.6	8.0	22.8	21.2	9.4	-	-	33.4	-
0.2	38.8	44.0	46.6	19.2	47.4	16.8	17.8	23.0	9.2	11.8	20.0	21.4	11.8	31.8	-	-	-	43.2	43.2	-
0.3	50.8	50.2	45.0	34.6	24.4	26.2	40.6	10.8	8.8	33.0	31.8	-	9.0	40.0	21.6	-	52.6	9.8	-	10.2
0.4	44.8	32.0	25.0	41.2	16.4	41.8	-	11.2	16.8	25.0	31.6	33.2	28.6	56.4	-	-	-	-	-	-
0.5	11.4	27.0	42.8	27.6	34.2	11.6	9.0	26.0	17.6	9.2	10.6	-	-	-	-	29.2	-	-	-	-
0.6	26.8	43.6	35.0	32.4	8.8	42.8	13.6	33.0	-	25.6	22.4	9.0	-	-	-	-	11.0	-	-	11.0
0.7	21.4	50.2	41.4	27.4	19.2	26.0	12.0	30.8	11.4	18.4	11.8	-	34.8	-	22.0	-	21.2	11.2	24.0	25.0
0.8	46.2	19.4	27.4	37.2	21.0	25.0	9.8	17.6	-	17.8	-	-	-	-	-	19.8	-	-	-	-
0.9	42.2	36.4	42.6	36.4	15.0	30.8	8.8	16.2	18.2	10.4	-	-	-	-	-	-	-	-	-	11.0
1.0	28.2	47.6	34.6	8.6	-	44.2	31.0	29.8	8.2	-	19.4	-	-	-	-	-	-	-	-	-

As the relationship ratio goes higher, agents tend to have dependence chain that ends up in a loop (dead lock) where the coalition formation is not feasible. The increase in the AND-Dependence ratio does not affect the feasibility of the coalition formation much, except for computation time. Fig. 4 shows the total value of the coalition formed with a society size of 10 agents and the basic payout of 40 and 60.

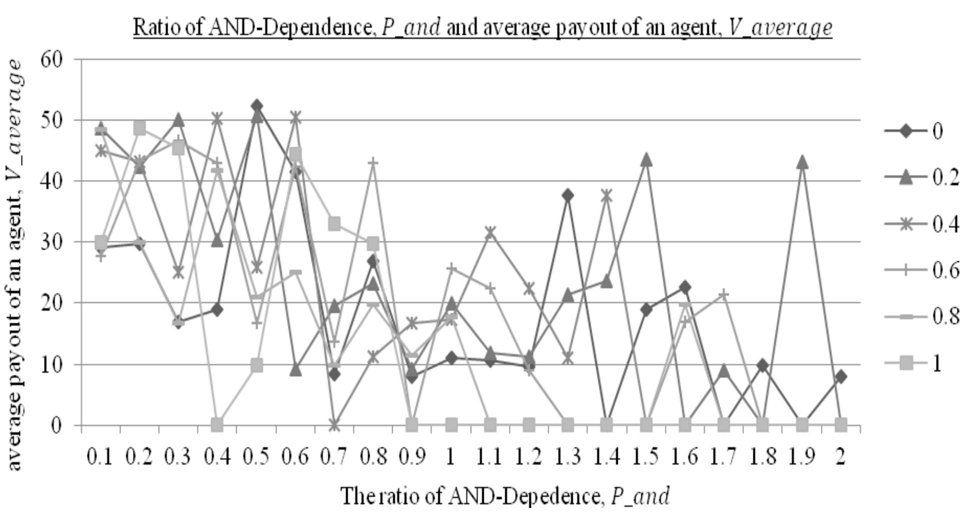

Fig.4: Ratio of AND-Dependence, P_{and} and average payout of an agent $V_{average}$

There is some noise during the process of CF as there may be some "deadlock" issues. The main reason is the data for this experiment are generated randomly. The authors intentionally include this particular constraint in the experiment as it will add a dynamic element to the simulation. The graph in Figure 4 shows a running series of the simulation that considers multiple randomized datasets. Based on the simulation results, a few observations can be deduced, as follows:

- Observation 1: The increment in the AND-Dependence ratio P_{and} causes the coalition formation to fail easily.

The increment of the AND-Dependence ratio P_{and} shows that the agent has to consider all the agents engaged in the dependence relationship. There are two fail outcomes of CF which include: (1) insufficient budget to form coalition and (2) agents refuse to cooperate and there are no alternative options. The AND-Dependence relationship has a strict condition for the dependence relationship that all agents in the dependence relationship have to agree to join the coalition. If one of the agents rejects the offer, the CF will fail easily. The budget v has a major influence on CF as it holds the threshold for it. If the budget v is insufficient, CF will fail instantly. Fig. 4 and Table 4 have shown the increment of the AND-Dependence ratio P_{and} will cause CF to fail easily. This observation has been shown in Hypothesis 2.

- Observation 2: The increment of the relation ratio P_a causes CF to fail easily.

The increment of the relation ratio P_a indicates the number of dependence relationships in the coalition increases. The relationship includes the number of AND-Dependence and OR-Dependence in the process of CF. The increase in the dependence relationships indicates that the coalition is much harder to form due to the complexity of the relationship. Hence, the CF process has a tendency to fail. An observation of Table 4 shows that the relation ratio $P_a = 2.0$ consists of eight failed attempts of CF. By comparing the relation ratio $P_a = 2.0$ and relation ratio $P_a = 1.0$, the failure rate can be easily distinguished based on the relation ratio. By concluding Observation 2, Hypothesis 1 has shown the influence of the relation ratio P_a towards successful CF.

- Observation 3: The ratio of OR-Dependence P_{or} encourages the coalition formation in the society.

The ratio of OR-Dependence P_a shows increasing chances of an agent to choose an optimal partner. The increment of the OR-Dependence ratio P_a shows that the ratio of AND-Dependence P_{and} decreases. As the ratio of AND-Dependence P_{and} increases in Figure 4, CF tends to fail easily. This situation can be denoted as the AND-Dependence consume majority of the budget v to maintain the stability of the coalition. Due to limited budget, the CF will fail as the budget for the allocation is insufficient. This is on the contrary to the AND-Dependence scenario, where the increment of the OR-Dependence ratio P_{or} has a higher rate of CF. Agents can sorely depend on the most convenient agent for CF. Hence, the computational complexity of the OR-Dependence will be low as compared to the AND-Dependence. Based on the analysis above, we can denote that Hypothesis 3 is proven.

CONCLUSION

T-DepExp system has become the framework for developing the budget mechanism in providing a better mechanism for transitive based coalition formation. It has been proven to generate feasible coalition with various numbers of budgets, where traditional method such as the Shapley value does not perform well in large-scale society. In searching of an ideal formula for expressing the required budget for the transitive dependence based coalition, various types of simulation and extensions will be implemented for future work.

In future agenda, the T-DepExp system will simulate CF based on an optimal budget in order to form feasible coalitions. The authors will define the calculation of the cost for each action requiring other agents' capabilities. Furthermore, algorithm that enables the T-DepExp system to adapt to dynamic environment can be implemented anytime in the simulation.

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