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Political Science and Multi-Agent Simulation: Affinities, Examples and Possibilities

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Abstract. Domestic politics and international relations are fertile fields for the analysis using multi-agent simulation. Both theoretically and empirically, such a technique can serve the development of political science. To attract scholarly attention, some illustrative examples may be helpful. Herein, more or less realistic analyses of different types of interactions between different types of agents are outlined: (1) the White House during the Cuban Missile Crisis in 1962; (2) three-layered interrelationship between voters, politicians and political parties; (3) the long-lasted civil war in the Sudan; and (4) trade friction in interdependent world. Note that the same "simulator" was used in all those analyses. This multi-purpose "simulator," which has been developed in Japan, is introduced herein. Finally, some methodological possibilities are suggested.

1 Introduction

Agent-based simulation or multi-agent simulation (henceforth, MAS) is a promising method in analyzing political phenomena. Interactions between agents (either natural persons or nation-states) are essential in political behavior as compared with simple, price-taking micro economic behavior, for instance. In fact, numerous topics are suitable to the analysis applying MAS, and in recent years, an increasing number of researches have been conducted. On the other hand, however, they are produced by relatively a small number of researchers. In short, MAS is still a niche technique in political science. One of the obstacles that prevent a wider use of MAS is a doubt shared by many political scientists on the utility of simulation in general. However, the most serious obstacle seems the lack or short of skills to conduct MAS among political scientists. Compared with economics and sociology, political science is a discipline very distant from mathematical, numerical or quantitative methods, not to

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mention simulation. It is true that there are some interests in simulation, especially rapidly developing MAS, but it is yet to be disseminated. Few political scientists are familiar with programming technique to conduct MAS, while few collaborations with system/computer scientists has been attempted by political scientists.

We launched a research project in order to overcome such weak-points of most political scientists. Our approach is not to enhance computer literacy of political scientists, but to make computer technology closer and friendlier to them (more precisely to us including myself). Specifically, our aim is three-fold. First, to develop a user-friendly and multi-(if not omni-)purpose platform for MAS. Second, to analyze different types of social order through MAS. Third, to promote political analyses using MAS, and to encourage political scientists to try MAS in their respective research. Our endeavor is under way, and a few results can be shown.

2 Affinity of Political Phenomena for Multi-Agent Simulation

Politics is associated with power, control and authority. A ruler orders subordinates in a state; a leader directs followers in a company; major powers dominate smaller nations in international society. Such regulatory characteristics found in politics seem remotely related with the subject of MAS. There is another aspect in politics, however. It is the interplay between actors, each of which attempts to influence others; it is an art of collective choice; and it deals with social dynamics between chaos and order. There are a lot of cases that are suited for the analysis applying MAS. While Johnson(1999) conducted an extensive survey of simulation modeling in political science, the following attempt is to identify some promising fields of political science for MAS, and to point out relevant works with special reference to the outcome of our research project and to works done in Japan.

2.1 Political Theory

Emergence of social order is the central theme of political theory. Once the God-given order of *respublica Christiana* disappeared some centuries ago, alternative logics, more or less rational, have been formulated until even today. Namely, when the order was badly needed during the turbulent period of early modern Europe, a set of theories was developed by such philosophers as Hobbes, Locke and Rousseau, to name a few, which is now classified into the Social Contract Theory. Those classical theories are contending with one another, and Yamamoto(2002) evaluated the compatibility between their premises and dynamic outcomes based on them, by reinterpreting Hobbesean and Rousseauistic logics by MAS.

In general, political theory is to be developed by MAS-related studies. Within political science, political theory is most (in fact, purely) formal. Therefore, it is easy to translate the argument into the computer model. More importantly, political theory employs a bottom-up approach in the sense that it is concerned with the linkage between interactions among individuals, who are equal in nature, on the one hand, and the pattern of social order that emerges from the interaction on the other. Furthermore, MAS-based studies are free from oft-mentioned criticism against MAS on the short of empirical relevance because political theory is so axiomatic that only theoretical relevance matters. The pioneering analytical works on the tit-for-tat strategy in the prisoners' dilemma (PD) games by Axelrod(1984, 1997) can be classified into this category, although his methods and conclusions were later

criticized, for instance, by Shimizu(1996) and Yasuda(2001).

2.2 Democracy

Democracy is an idea, and an institution as well, that formulate more or less binding social rules by transforming conflicting opinions or positions borne by different individuals into one authoritative conclusion on various issues. Political scientists have been concerned with various types of questions on how to make democracy work democratically. In this regard, one of the fundamental questions that are relevant to MAS is how to better represent a variety of interests borne by numerous citizens. The well-studied paradoxes of voting are classical and ideal examples demonstrating that the way of bottom-up aggregation of individual preferences affects social/collective outcomes. The search for better election systems has been another important subject that connects agents (voters) and collective will. Recent works include (Bhavnani 2003), (Bissey 2004) and (Kottonau and Pahl-Wostl 2004).

The public opinion plays important roles in democratic politics, and is certainly a promising subject to study by MAS. Based on the social impact theory (Latane and Wolf 1981), Nowak et al.(1990) simulated the change in individual attitudes and the formation of public opinion. In general, interactions between citizens and impacts of mass media are the two major subjects of concern.

2.3 Nationality and Ethnicity

American independence of England and French Revolution trumpeted the beginning of the age of nationalism. Since then, the politicization and mobilization of populations has become the main theme of politics. Nationalism involves thousands and millions of individuals in political arena. Culture and collective identity is brought in. In nation-states, ethnicity often plays a centrifugal role in domestic politics, and sometimes leads to ethnic conflicts. Civil wars are thus concerned with nationality and/or ethnicity of the people.

Politics of collective identity is the subject where MAS is widely applied. Axelrod(1997), Cederman(1997), Lustick et al.(2002) and Srbljinovic et al.(2003) show different but related approaches to analyze collective identity, and influenced following studies. Mitsutsuji(2002) illustrated the relationship between prevailing types of political movement and the geographical distribution of ethnic communities. Yamamoto(2004) extensively dealt with theories of nationalism, and evaluated the relevance of each theory based on MAS of cultural dynamics of populations.

2.4 International Relations

International Relations may be most suited for MAS-based studies. By definition, there is no single authoritative power in international society, and international affairs are the outcome where nation-states interact with one another so as to make alliance, war, and regimes. In fact, probably the earliest attempt of MAS in the field of political science was planned in the 1960s by Bremer and Mihalka(1977). The idea was further developed by Danno and Tanaka(1992) and Yamamoto et al.(2002). Those studies are concerned with the stability of balance of power, and the probability of the emergence of the empire. There are of course other types of MAS-based studies in International Relations. Yamamoto(2003) extensively surveyed and discussed the application of simulation techniques including MAS in the study of international relations.

Among various possible subjects, dynamics of international regime seems most promising. For, international regime is formed from the bottom rather than given by a supranational authority. The formation of regime, and the maintenance, is often related to the existence of the hegemonic power which can take lead and pay cost, but it is certainly the outcome of interactions between independent agents. In MAS-related studies, Kimura and Oda(2002) discussed the desirability of different types of regime in managing the greenhouse effect gases, and Hishiyama(2002) dealt with private regime of transnational telecommunication.

2.5 Some Illustrative Examples

As shown above, there are various fields of political science that are particularly appropriate for the MAS-related analysis. Needless to say, the above-mentioned fields are by no means exhaustive, and MAS can be employed in other fields, too. On the other hand, the application of MAS to political science will be promoted more easily if some illustrative examples are shown. They may provide prototypes of related studies, or may enhance imagination and insights toward MAS.

In this paper, four examples are outlined as shown below. Different types of MAS are intentionally selected from the models we have been constructing in the on-going research project so that a wide range of applicability of MAS can be shown. While the description is sketchy, they will hopefully suffice to illustrate the potentials of MAS.

3 Watershed at the Cuban Missile Crisis: Inside the ExCom

The Cuban Missile Crisis of 1962 was the most serious world affairs during the Cold War, and almost resulted in a nuclear war. The US Government chose "quarantine" –a kind of blockade of Cuba– out of six options, and succeeded in avoiding further escalation. Despite a huge number of memoirs and studies, it is unclear why and how that option was chosen. MAS may capture the characteristics of decision-making. Sakamoto and Hoshiro (2005) developed a model as follows.

3.1 Theoretical Background

To cope with the crisis, President John F. Kennedy convened the Executive Committee of the National Security Council (ExCom), whose members were the president's most trusted advisers (see **Fig. 3.1**). Various studies on this crisis decision have been accumulated, but few have successfully clarified the reason why "quarantine" was chosen. Even the most influential work by Graham Allison (1971, with Zellikow 1999), who attempted to explain the decision based on three alternative models, does not explain either frequent changes of individual ExCom members' views or the process of convergence to adopt quarantine.

In order to solve these problems, the "social comparison/ cultural value" theory was employed. It has been used explain the group polarization phenomenon in the field of social psychology (Brouw 1965; Stoner 1968; Myers and Lamm 1976; Olson and Suls 2000). The theory asserts that individuals in a given society, in addition to having their own views, recognize the majority's standard norms, and through group discussion and self-comparison, their views tend to shift toward a commonly accepted value. This logic was implanted into the model.

3.2 Overview of the Model

The main purpose is simulating the process of decision-making among ExCom members. Since there was one week for them to make decision, the model focuses on that period from the 16th of October when the CIA reported that the Soviet Union was placing offensive missiles in Cuba, up to the 22nd when JFK announced publicly that the US had decided to respond to the Soviet action with a naval quarantine of Cuba.

The model was designed to reflect the reality so as to allow the virtual ExCom members to change their views dynamically through their discussion. The individual agents' behavior was ruled by the above-mentioned "social comparison/ cultural value" theory. Assuming that there were six options from "Do Nothing" as the most cautious option to the riskiest, "Invasion", the simulation tested what opinions individual members originally had, and how those views shifted toward the majority's opinion throughout the one-week discussions.

3.3 Simulation Results and Implications

One of the most interesting results was that "Quarantine," which was chosen in reality, was as probable as a riskier option, "Air Strike" (**Fig. 3.2**). That is to say, the US Government could have adopted the policy that might lead to the war with more or less equal chance. Based on the realistic model, the counter-factual discussions can be done: for example, if the Secretary of State had been a dedicated pacifist, or if the Secretary of Defense had been a warmonger, how would the result have been different? Our experiments show that while the former would have led the group view to be more cautious, the latter would not have affected the result only delaying the convergence of their views.

4 Electoral and Party Systems: Voters, Politicians and Parties

While the concept of liberal democracy is widely shared, democratic countries have different political institutions. In other words, there are different combinations of electoral systems and different party systems. There exist various arguments about the relationship between electoral and party systems. Mitsutsuji (2003, 2004) conducted MAS in creating an artificial political society as follows so as to explore this controversy.

4.1. Theoretical Background

Most famous and classical hypothesis is provided by Duberger(1954), which is the single-seated electoral district system generates two-party system. Empirical researches cast doubts about this causality. However, electoral system is said to be one of the most important factors that decide party system. It is assumed to influence political parties' and politicians' behavior strongly. What kinds of differences are brought about by the difference of electoral system?

4.2. Overview of the Model

In order to test the arguments, the Artificial Political Society (APS) was constructed in order to simulate dynamic interactions among voters, politicians and political parties. APS is made on the two-dimensional opinion space, which represents two issues of political preference: urban-based vs. rural-based along the vertical axis, and

right wing vs. left wing along the horizontal axis. On the opinion space, three different types of agents (voters, politicians and political parties) interact with one another. Voters vote the politicians according to the similarity of preferences; elected politicians organize, join or transfer political parties; and political parties try to attract voters in order to win the election.

While they interact with one another, all move on the opinion space, i.e., change their political preferences, in either centrifugal or centripetal way depending on mutual relationship. Big swarms of voters may emerge around parties, which consequently consist of many politicians. In an opposite way, politicians' splits cause division and change in parties' opinions, which may dissolve a voters' swarm.

By dividing voters and candidates into electoral districts, electoral system is introduced into APS. For example, three types may be compared: the one district system of fifteen seats, the medium constituency system of five three-seat districts and the single-seat electoral district system of fifteen districts.

4.3. Simulation Results and Implications

The average number of parties under different conditions is shown in **Table 4.1**. It indicates that electoral system does not have significant impacts on the number of parties. Instead, other factors, such as easiness for politicians to change their party membership or easiness to form new parties, have more significant impacts on the number of parties.

The above findings do not mean that electoral system has insignificant impacts on politics. In APS, electoral system influences the distribution of politicians' opinions. **Figure 4.1** shows a typical distribution of politicians' opinions under the single seated district system and that under the one district system. Under the single seated system (left), because politicians have to fight for only one seat in each district, they tend to come closer to the center of voters' swarm. Under the one district system (right), on the other hand, because politicians who are not positioned at the center of voters may survive, politicians tend to spread over the swarm of voters, and their opinions vary to some extent.

5 Civil War and Mobilization: Real Sudan vs. Virtual Sudan

In failed/collapsed state, violent conflict is often associated with ethnic mobilization. Hence, the pattern of civil war tends to be determined by geographical setting of ethnic communities. The Sudan is a typical case: a multi-ethnic (racially, linguistically and religiously) country that suffered from civil war for more than two decades. Sakamoto (2004, 2005) examined the Sudan's uprisings through MAS by creating an artificial Sudan as follows.

5.1 Theoretical Background

Domestic conflicts are almost always accompanied by the mobilization process, a process in which inhabitants are politically mobilized by government and insurgent organization(s), thus dividing their country. Theoretical approaches to such conflicts have treated these divisions as given and static: they have seen conflicts within a context of some relationship between given social and/or cultural groups, each of

which is derived from some common traits (e.g., ethnicity, religion, class). Many conflicts, however, are not so clear-cut, requiring dynamic analysis of the group formation process brought about by mobilization.

Axelrod's model of cultural dissemination (1997) and Cederman's model of nationality formation (1997) are pioneering attempts in the analysis of such phenomena. Reflecting the above theoretical concern, two kinds of simultaneous interactions during conflict, i.e. armed battles among organizations and mobilization of inhabitants by respective organizations, should be interrelated with each other.

5.2 Overview of the Model

A "virtual state", consisting of territory, inhabitants, and government, is to be constructed in computer, and rebellions take place somewhere in the territory stochastically. The inhabitants are spatially distributed over the territory and differentiated from each other according to several social/cultural traits. While fighting each other, the government and the insurgent organizations mobilize the inhabitants by manipulating "symbols" in order to acquire necessary supports and resources.

This general model is applied to the civil war in the Sudan since 1983. Based on ethno-linguistic and religious distribution maps, the virtual Sudan was constructed as an approximation of the real country (**Fig.5.1**).

5.3 Simulation Results and Implications

As for the Sudanese civil war, MAS should elucidate and connect the following two aspects: (1) the prolonged division of territorial rule between the northern-based government and the southern-based insurgent organization, the SPLA (Sudan People's Liberation Army), and (2) the political aspect of this division, namely the competition between the ethnically and religiously exclusive government and the ethnically and religiously inclusive insurgents. The latter aspect has made it difficult to consider the former as resulting from the often-referred ethnic and religious divides in the Sudan.

The simulation results show that these two aspects of the conflict can emerge even in the virtual and simplified environment (see Fig.5.2), and their analyses suggest that the two are indeed inseparable. One of the important implications is that both of the inclusive and the exclusive symbols upheld by the two antagonists have some "fitness" (i.e. difficult to uproot) in their respective localities, leading to the political, as well as military, deadlock in the country.

6 Managing Interdependence: Absolute or Relative Gains?

Different recognition of national interests can result in different behavior, and thus in different international order. The well-known rivalry between neo-liberalists and neo-realists is examined by Suzuki (2003, 2004) in the case of the linkage of trade negotiation and international trade regime as follows.

6.1 Theoretical Background

If concerned with absolute gains alone, the state is interested only in its own wealth, and hence evaluates trade agreements regardless of other states' gain. Based on this assumption, neo-liberals (and orthodox economists) assert that creation and maintenance of an open world trade system is possible, with the help of the repetition

of interaction and/or configurations of global wealth (Keohane 1984).

Proponents of relative gains, mostly political realists, claim that cooperation among states is not so easy. They insist that the most important objective of a state is to survive, and that power, which matters in relation to others and thus is a relative concept, counts for its behavior. States often refuse to make an agreement that favors the opponents more (Grieco 1988, 1990). Therefore, the resulting trade system is expected to be less open.

Then, if virtual states with absolute/relative gains are engaged in trade negotiation with one another, do they create orders predicted by these theoretical considerations? Which assumption generates the result closer to the reality?

6.2 Overview of the Model

Each state is concerned with its trade dependency, bargaining power, and optimal trade dependency from its economic size and current amount of trade. The state calculates them based on well-accepted premises: smaller nations tend to favor higher trade dependency; small and dependent nations have less bargaining power; profit from trade enlarges the size of economy, etc. In the next phase, every state randomly selects a negotiating partner, and begins negotiation to increase/decrease the amount of trade between the two. If preferences of the two coincide, they agree. If not, the stronger will prevail. However, the state pursuing its relative gain avoids agreements if the counterpart gets too much in comparison with own. Although the negotiations are bilateral, each state usually carries out trade multilaterally (**Fig. 6.1**).

6.3 Simulation Results and Implications

The result is surprising. Contrary to intuitive or theoretical prediction, trade dependency is the higher when states maximize relative gains than otherwise. The same result is observed even when the contribution of trade to economic growth is set at zero. Moreover, not only the ratio of trade but also the total real amount of trade was larger.

Fig. 6.2 shows the resulting patterns. In a world where states pursue absolute gain (**left**), all states line up on the most prefered trade dependence. The larger is the state's market, the lower the dependence. This is what states want, and all economies increase in size although smaller states tend to grow more rapidly. When states pursue relative gain (**right**), trade dependence of large states are almost same as those in absolute one. However, the small states' dependence tends to deviate greatly from the optimal points, in both upper and lower directions, and their economic growth is hamperd by excessive or insufficient trade. The only difference between the two cases is that states pursuing relative gain do not agree to certain deals that those pursuing absolute gain agree. Small difference of operational rules seem to create very different orders. This result implies the need to test theories and premises in the context of interplay of agents. Though the empirical figure is not shown, the right figure is similar, which suggests that national leaders are more concerned with relative gain.

7 JAVA KK-MAS: a User-Friendly, Multi-Purpose MAS Platform

Believe or not, all of the above four examples of MAS-based studies employ the same software package for MAS. This simulator is called "KK-MAS" that was originally

developed by the Kozo Keikaku Engineering (KKE) some years ago. Now, with the close collaboration of the KKE, we have been developing "JAVA KK-MAS." Since April 2005, JAVA KK-MAS has been under the field test.

7.1 Need for a User-Friendly, Multi-Purpose MAS Platform

There exist some tools for MAS, but some difficulties are found to use them. For example, Starlogo is a very user-friendly simulator, but is not suitable to carry out academic investigations. On the other hand, Swarm can be used for developing complicated models, but it requires knowledge of the Objective-C language, which is a high barrier for most of social scientists. Repast, which was developed at the University of Chicago and Argonne National Laboratory, is now prevailing. Truly it is easier than Swarm, but it still requires the knowledge of the Java language. This object-oriented language is also difficult for social scientists to learn.

In order to overcome those linguistic and mathematical barriers, KK-MAS was developed so user-friendly as to meet potential demand of social scientists. KK-MAS requires minimal knowledge of programming languages so that those who understand the BASIC can develop complicated models that are suitable for social sciences.

7.2 The Concept of JAVA KK-MAS

JAVA KK-MAS was designed to realize four objectives simultaneously: (1) to make model building as easy as possible, (2) to enable to construct as many types of models as possible, (3) to make analytical power as high as possible, and (4) to operate on various types of computers. While the original KK-MAS operates only on the Microsoft Windows OS, JAVA KK-MAS is programmed by the Java language, and therefore not dependent on the OS. The user does not have to know of the Java language. The only thing the user has to do is to build models simply by writing some "rules" in a BASIC-like manner.

As for the model, the generic structure is hierarchical ("universe"-"space"-"agent"), and the user is asked to create one or more spaces and one or more agents of one or more agent-types. Various functions are provided to support model building. The simulator controls and carries out all the process of simulation according to the model built. On JAVA KK-MAS, simulation can be executed, displayed and saved under various optional conditions that the user can choose.

JAVA KK-MAS has various advantages over Windows KK-MAS in addition to the fact that it can be installed on various OS platforms. In general, it has become more user-friendly, more flexible and more powerful. Some of the major improvements that have been implemented thus far include (1) a more strictly controlled scheduling of executions, (2) the definition of space and direction consistent with ordinary mathematical expressions, and (3) various functions for debugging. Those who are associated with academic institution, such as professors, graduate students and undergraduates, can participate in the on-going field test. Readers are encouraged to join (http://www.kke.co.jp/iit/mas/index.html).

8 Possibilities of MAS

MAS has been introduced to social science in recent years, and many directions for

MAS-related studies are yet to be explored. With new innovations in method and technique, novel uses of MAS may be invented.

8.1 From Multi-Agent Simulation to Mega-Agent Simulation

Although information technology is developing very fast, and the computer performance is becoming faster and smarter, it takes impracticably long time to conduct MAS as the number of agent increases. There are many MAS's in which tens of agents or hundreds interact each other; there are some MAS's that make thousands of agents interact. In order to simulate a cell automaton of 100x100, one has to build a model of ten thousand agents, and the execution of simulation may take hours depending on the complexity of interactions. In fact, there are few MAS's in which tens or hundreds of thousand agents interact. An exceptional MAS was carried out by Lomborg (1996) where more than a million agents interact more than 300 thousand times in a single run.

Once Mega-agent simulation, i.e., MAS involving millions of agents instead of thousands, becomes practical to conduct, the analysis of artificial society will change qualitatively, not to mention quantitatively. A big city or a small nation-state can be represented within the computer. Such technology is already used in analyzing the formation of a galaxy, or forecasting the weather next day or the climate next decade. A user-friendly mega-agent simulator may be developed for social scientists in near future.

8.2 Hybridization: Human-Agents Play with Artificial-Agents

Another possibility would be the hybridization of MAS, in which human players interact with programmed agents. Despite that the original KK-MAS or JAVA KK-MAS is not developed especially to build hybridized models, hybridization is possible. Hybridized models can be in fact built on the simulator in hand. In fact, a hybridized MAS model of the PD game has been built by Suzuki (forthcoming). This model creates a world of computer and human agents who are engaged with each other in the iterated PD game in a manner similar to Axelrod's well-known PD-strategy contest (1984). All agents, including one human player, are paired and play the game.

In this particular model shown in **Fig. 8.1**, seven computer agents identified as 00 through 06 and a human player (identified as 07) make 4 pairs, and each individual makes 50 choices before the pairs are changed randomly. In the default setting, the pay-off for mutual cooperation is 1 point, and 0 point for mutual defection. If one player defects while the other cooperates, the former gets 2 points and the latter loses 1. At the outset, each computer agent chooses one strategy from 10 famous strategies, such as All-C, All-D, Tit-For-Tat, Friedman, Tullock etc. In this case, "0" as indicated, the strategy is randomly chosen for all computer agents. Three small windows in **Fig. 8.1** show the latest result for the human player, total scores, and current pairs. On the right side there is the control panel for inputting the human player's hand, and for designating computer agents' strategies.

The model is so flexible that the model-builder (game-supervisor) can change the gaming environments. The human player may or may not know the strategies of the other agents. It is easy to change the gaming conditions: to randomize the number of iteration, to specify, change or randomize the strategy of computer agents, to change the score of pay-off matrix, etc.

Doubtlessly, this model (and probably hybridized MAS in general) is suitable for educational purposes. By participating in the simulation, one can experience and better understand the situation. For example, understanding the nature of the PD and possible strategies from a textbook may be challenging task for a kid, but if he/she is thrown into virtual jail and face the choice, the situation would be immediately clear to him/her, which can be called a "serious game". Alternatively, high school students may learn the importance and the difficulty of cooperation in global environment problems.

As for scholarly purposes, hybridized MAS may be useful in analyzing the nature of human decisions. Testing human players in anonymous or identifiable PD games to see how he/she reacts would be one example. Discovering a more human-like strategy would be another possibility. Just as we learn from computer simulations, so do the computer agents from us. If we use genetic algorithms, computer agent would learn strategies from human players, and this in turn might be utilized for better understanding of human behavior.

8.3 Concluding Remarks

There are fertile fields of political science for MAS. More political scientists will hopefully become interested in MAS-based analyses of political phenomena, and they will use MAS in their respective research topics. With user-friendly software for MAS, this new analytical method would be used oftener and more extensively, and would be recognized as useful. JAVA KK-MAS is being developed so as to be one of such tools. This and other simulators will provide political scientists with a new horizon of research.

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Tables and Figures

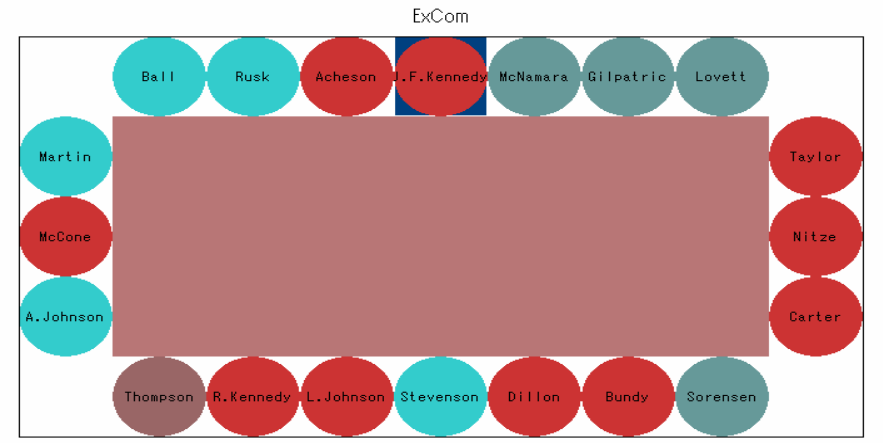

Fig. 3.1. The ExCom. Not all members continuously participated in weeklong discussions.

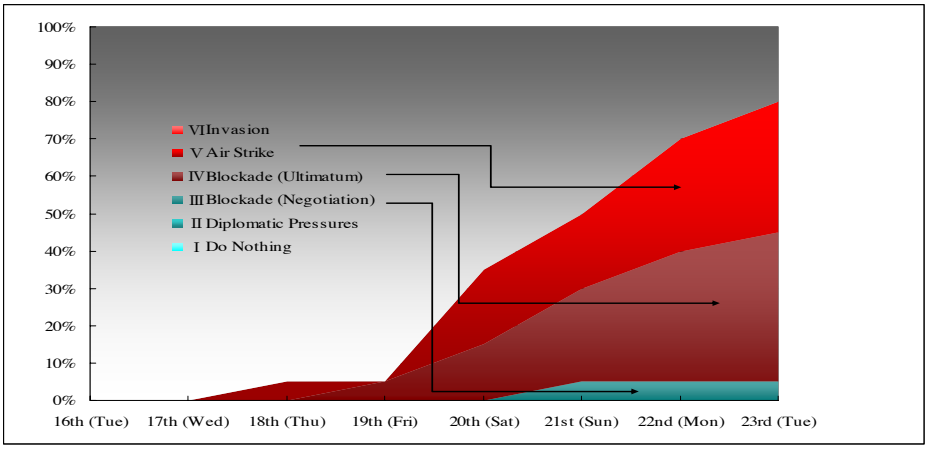

Fig. 3.2. Majority opinion formation: change of the frequency distribution of majority opinions. This is the result of twenty trials.

Table.4.1. Average Number of Political Parties on Various Conditions

		Change of Party Membership			
		Difficult(St=0.9)		Easy(St=0.1)	
Party Formation		Party's Influence		Party's Influence	
		High	Low	High	Low
	Easy(F=0.9)	5 P S M 0	5 M S P 0	5 SMP 0	5 SMP 0
		Party's Influence		Party's Influence	
		High	Low	High	Low
	Difficult(F=0.1)	5 S M P 0	5 P M S 0	5 S M P 0	5 S M P 0

* Voter 1000, Seats 15, 10 times Elections
* S = single seated electoral district system (15 seats/ 15districts)
* M = medium district system (15 seats/ 5 districts)
* P = one didtrict system (15 seats/ 1 district)

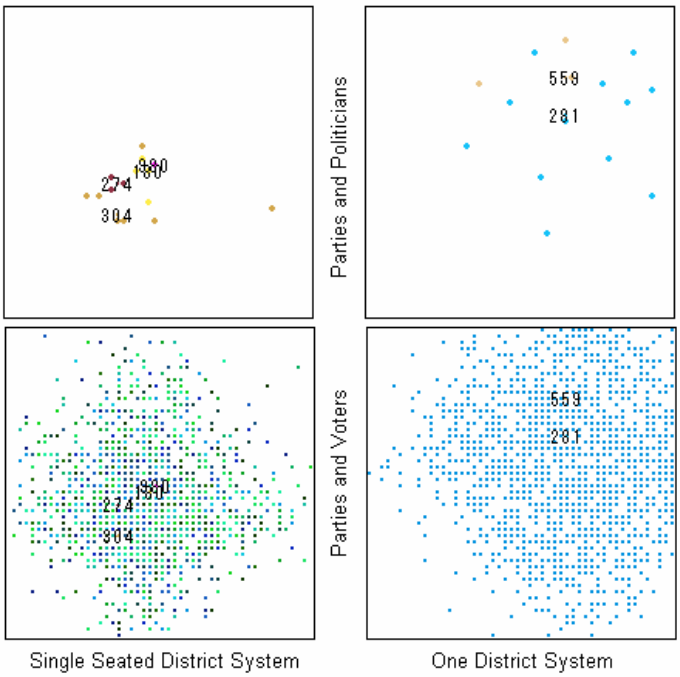

Fig. 4.1. Distribution of Voters, Politicians and Parties under the Single Seated District System and the One District System. Numerals denote political parties' ID.

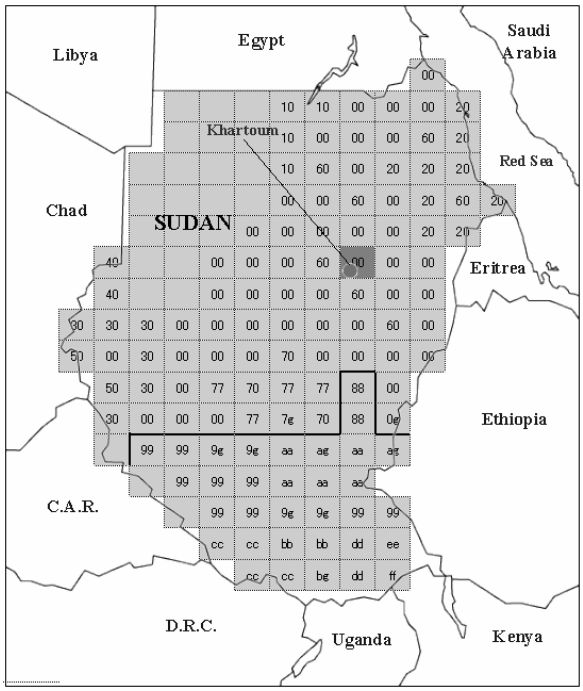

Fig. 5.1. The Virtual Sudan. A 2-digit string on each cell represents ethnicity and religion of the corresponding agent ("community"). For example, a "9g" community is ethnically Dinka ("9") and religiously Christian ("g"). Empty cells denote uninhabited areas.

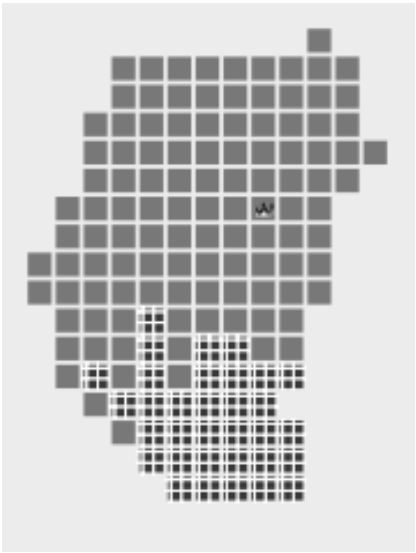

Fig. 5.2. Territorial division of the virtual Sudan (a typical case)

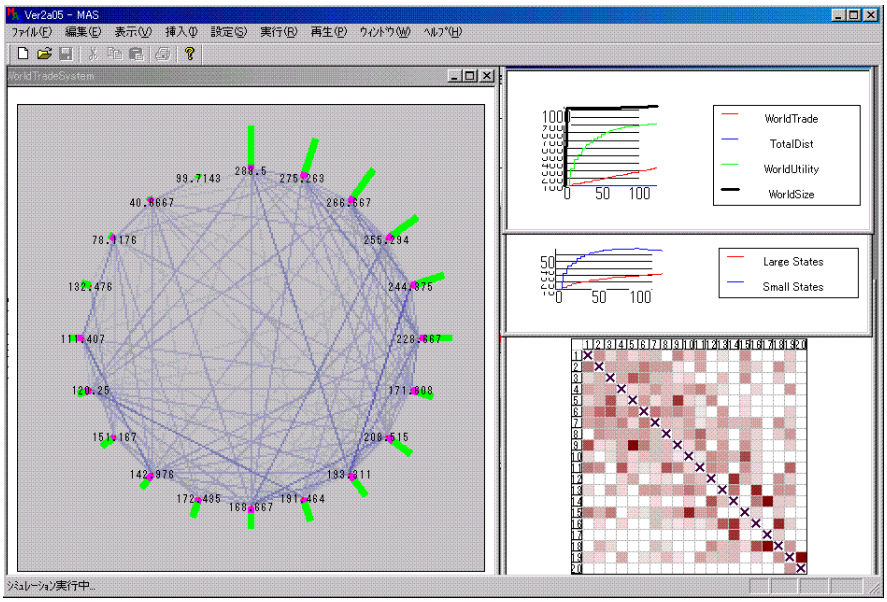

Fig. 6.1 The Trade Negotiation Model. The bar on each node shows its size and trade dependency, and the thickness of the lines between them indicates the amounts of trade. Diagram on the lower right shows each state's dependency on the others.

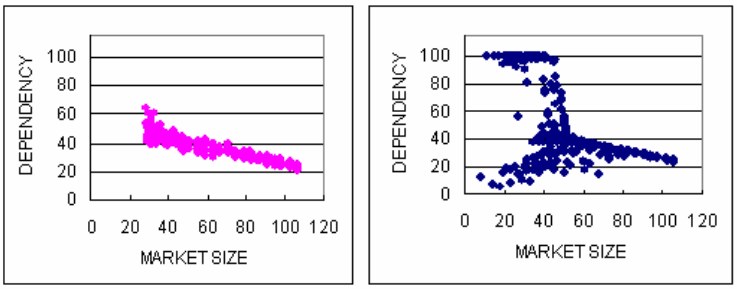

Fig. 6.2 Market size and dependency. States with absolute gains (left), relative gains (right). The simulation is run 50 times and each run contains 200 rounds of negotiations.

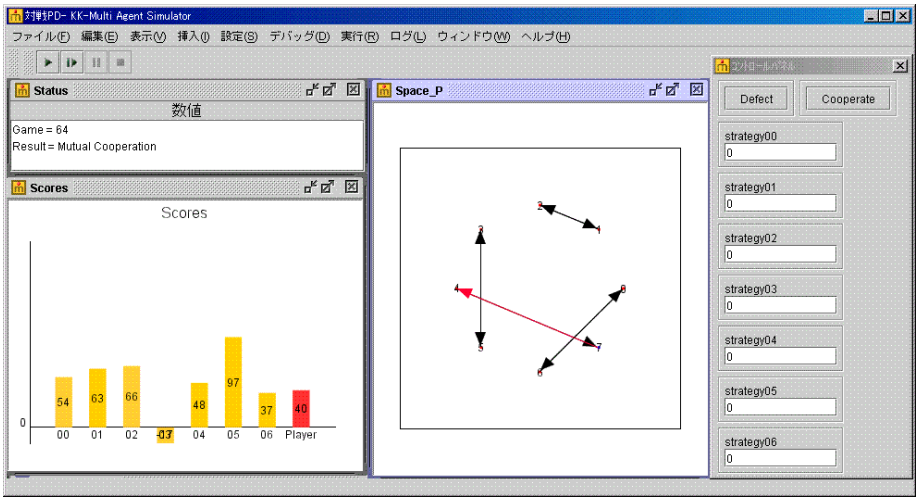

Fig. 8.1. Hybridized Prisoner's Dilemma Game. The human player chooses his/her hands by clicking the button "Cooperate" or "Defect" on the control panel (upper-right).