Optimizing conflicts in the formation of strategic alliances

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Abstract. Coalition setting among a set of actors (countries, firms, individuals) is studied using concepts from the theory of spin glasses. Given the distribution of respective bilateral propensities to either cooperation or conflict, the phenomenon of local aggregation is modeled. In particular the number of coalitions is determined according to a minimum conflict principle. It is found not to be always two. Along these lines, previous studies are revisited and are found not to be consistent with their own principles. The model is then used to describe the fragmentation of former Yugoslavia. Results are compared to the actual situation.

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1 Introduction

Physical concepts might prove useful in describing collective social phenomena. Indeed models inspired by statistical physics are now appearing in scientific literature [1].

The process of aggregation among a set of actors seems to be a good candidate for a statistical physics like model. These actors might be countries which ally into international coalitions, companies which adopt common standards, parties that make alliances, individuals which form different interest groups, and so on.

Given a set of actors, there always exists an associated distribution of bilateral propensities towards either cooperation or conflict. The question then arises as to how to satisfy such opposing constraints simultaneously. In other words, what kind of alliances, if any, will optimize all actor bilateral trends to respectively conflict or cooperation.

It turns out that a similar problem does exist in spin glasses. For these systems, magnetic exchanges are distributed randomly between ferro and antiferromagnetic couplings. Indeed such an analogy has been used in the past in a few models.

The first one is by Axelrod and Bennett (hereafter denoted as AB) [2]. They apply the physical concept of minimum energy to single out the stable coalitions within an configuration landscape. Later Galam demonstrated that the AB model is not fully consistent with its physical content. He then suggested a second model (hereafter denoted as G) based on both random bond and random site exchanges [3].

We propose here a qualitative extension of defining the coalition problem. While all previous approaches used

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implicitly a 2-side coalition dynamics, we allow multi-side coalitions. We indeed define the actual number of alliances as an internal parameter of the problem to be determined by simultaneously optimizing all bilateral propensities. While an Ising like variable may be appropriate to a huge number of problems both in physics and outside physics, there is no a priori reason to consider coalition dynamics restricted to a bimodal distribution.

We then apply our model to study the fragmentation of former Yugoslavia. Results are compared to the actual situation. We also revisit previous studies along this new scheme of not setting a priori the number of coalitions. As soon as the artificial bimodal constraint is relaxed, their results are no more consistent with reality.

Moreover, in physics models the exchange couplings and their distributions are known. In contrast, in the coalition problem the quantitative determination of bilateral propensities to either cooperation or conflict is a major challenge. We discuss this matter and argue that previous propensity calculations were too simplistic.

The rest of the paper is organized as follows. In the second part we review the AB and G models. The qualitative extension to multimodal coalitions is discussed in Section 3. On this basis, we revisit in Section 4 the cases of the Second World War and the Unix standard setting (studied in Ref. [2] and respectively [4]). The case of the fragmentation of former Yugoslavia is analyzed in Section 5. Concluding remarks are contained in last section.

2 Former models

2.1 The Axelrod-Bennett model (AB)

Axelrod and Bennett first attempted [2] to explain the composition of coalitions using some characteristics

of the involved actors (the elements of the system). The relative affinity between actor i and actor j is measured by a pairwise propensity p_{ij}, which is negative when they are in conflict and positive when they like to cooperate (with $p_{ii} = 0$). Differences in actor sizes are expressed by assigning to each one a weight factor s_i (a positive quantity). It may be a demographic, economic or military factor, or an aggregate parameter.

The creation of coalitions among the actors introduces a distance d_{ij} between each pair (i, j) of actors. It is 0 if i and j belong to the same coalition and 1 when they are in different coalitions. A given partition X of the actors into coalitions is equivalent to knowing all d_{ij}.

A "frustration" of each actor i is introduced to measure how much a configuration X satisfies its propensities. It writes,

$$F_i = \sum_{j=1}^{n} s_j p_{ij} d_{ij}(X) \ , \qquad (1)$$

where we considered a group of n actors.

Adding all actor frustrations, respectively weighted by their sizes, results in an "energy" of the system,

$$E(X) = \frac{1}{2} \sum_{i=1}^{n} s_i F_i \ , \qquad (2)$$

which is,

$$E(X) = \sum_{i>j}^{n} s_i s_j p_{ij} d_{ij}(X) \ . \qquad (3)$$

It is then postulated that the actual configuration of the system is the one which minimizes the energy. The path followed by the system into the coalition landscape space from an initial configuration follows the direction of the greatest gradient of energy. Once a minimum is reached the system does not change.

The AB model has been applied to the study of the alliances of the Second World War [2]. It was also used to study the standard setting coalitions formed by the companies which developed the Unix operating system [4].

Later Galam has demonstrated several inconsistencies of the AB model [5]. Here we found additional setbacks (see Sect. 4).

2.2 Galam reformulation of the AB model

Galam has shown [3] that in case of bimodal coalitions (A and B), the AB model is totally equivalent to a finite size non frustrated spin glass at zero temperature.

Accordingly, configurations can be expressed by the spin variables η_i, where the spin is $+1$ if the actor i belongs to coalition A and it is -1 if the actor belongs to B. The distances can be rewritten as $d_{ij} = \frac{1}{2}(1 - \eta_i \eta_j)$. The energy becomes,

$$E(X) = E_0 - \frac{1}{2} \sum_{i>j}^{n} J_{ij} \eta_i(X) \eta_j(X) \ , \qquad (4)$$

where $J_{ij} = s_i s_j p_{ij}$ and

$$E_0 = \frac{1}{2} \sum_{i>j}^{n} J_{ij} \qquad (5)$$

is a constant which depends only on the given sizes and propensities, but not on the configurations.

2.3 The Galam model (G)

Galam [3] introduced a new model for the case of bimodal coalitions where the two alliances have clear characteristics that would allow to define for each actor a natural belonging ϵ_i to each alliance. It is $+1$ if the actor i should be in coalition A, according to its own characteristics compared with those of A. It is -1 for B and 0 if there is no natural belonging to neither A or B.

In the G model, the benefit J_{ij} of cooperation or conflict between a pair of countries in either the same or opposite alliance is accounted for in addition to the local bond propensities G_{ij}. Both add together to a total propensity $p_{ij} = G_{ij} + \eta_i \eta_j J_{ij}$.

In parallel, forces (like military or economic mechanisms) by which each coalition as a whole couples to the orientation of a given actor are expressed in terms of an external field β_i. It contributes to the overall conflict through the product $\beta_i b_i \eta_i$, where $\beta_i = \pm 1$ represents the direction of the force that acts on actor i (towards A or B), while $b_i > 0$ is the amplitude of this force. The total energy of the system sums up to

$$E = -\frac{1}{2} \sum_{i>j}^{n} (G_{ij} + \epsilon_i \epsilon_j J_{ij}) \eta_i \eta_j - \sum_{i}^{n} \beta_i b_i \eta_i \ . \qquad (6)$$

This model has been used [3] to explain the stability of alliances during the cold war, with opposing NATO and Warsaw pacts. The fragmentation of Eastern Europe which resulted from the Warsaw pact dissolution as well as the simultaneous western stability was recovered within the model. The European construction *versus* stability and the Chinese stability were also analyzed within the same model [3].

3 Beyond previous models

3.1 A new approach: going multimodal

In physics, the symmetry of the internal degrees of freedom of a given system is clearly determined from specific measurements on the studied material. In particular, most magnetic systems may be modeled using a spin variable. It can be, among others, a 2-state Ising variable, a q-state Potts model, a XY spin with planar symmetry, or a Heisenberg spin with continuous symmetry.

In the case of human systems, the *a priori* restriction of using an Ising variable has no ground. Some known coalitions exhibit more than 2 simultaneous alliances, though

not much more. For example, the users and the producers of personal computers can be divided in at least three categories, with regard to the operating system they use (Windows, Mac OS, Linux \ Unix); there were three groups that fought each other between 1941 and 1945 in the space of ex-Yugoslavia: the Chetnik guerilla groups, the Communist partisans and the Nazis [6]; and in most democratic countries there are more than two independent political parties.

We extend previous approaches by allowing for multimodal coalitions. We assume the number q of coalitions to be an internal degree of freedom to vary from 1 up to n. Before, q was arbitrarily fixed to 2. The spin variable η_i can thus take q different values. Distances are expressed as $d_{ij} = 1 - \delta(\eta_i, \eta_j)$ and the energy is

$$E(X) = 2E_0 - \sum_{i>j}^{n} J_{ij}\delta(\eta_i(X), \eta_j(X)) , \qquad (7)$$

where E_0 is given by equation (5). This corresponds to the q state Potts model [7]. The initial expression of the energy, equation (3), can still be used.

To demonstrate that the increase in the number of allowed coalitions may reduce the energy of the system, we will discuss the example of a system with $n = 3$ actors. We assume $J_{12} = J_{23} = J_{13} = -1$.

If we impose only one coalition, the energy is 0. If we impose two coalitions, the minimum energy is -2 and is three times degenerated (the system is frustrated). If we don't impose a fixed number of coalitions, the system sets itself in a configuration with three different coalitions (all the actors are independent), with an energy -3, the lowest energy possible.

3.2 Gauge transformations

Let us consider a transformation of the distances as $d'_{ij} = a\,d_{ij} + b$. The energy becomes

$$E'(X) = \sum_{i>j}^{n} J_{ij}d'_{ij}(X) = a\,E(X) + 2b\,E_0 . \qquad (8)$$

If $a > 0$ this transformation keeps unchanged the dynamics of the system.

An interesting transformation is given by $d'_{ij} = 2d_{ij} - 1$. That is $d'_{ij} = -1$ if i and j are in the same coalition and $d'_{ij} = 1$ if not. For bimodal coalitions, we have $d'_{ij} = -\eta_i\eta_j$. The energy expressed with this distance accounts equally for conflict and cooperation.

Another interesting transformation is $d''_{ij} = d_{ij} - 1$, which gives $d''_{ij} = -\delta(\eta_i, \eta_j)$. In this case the energy is exactly the Potts energy,

$$E''(X) = \sum_{i>j}^{n} J_{ij}d''_{ij}(X) = -\sum_{i>j}^{n} J_{ij}\delta(\eta_i(X), \eta_j(X)) . \quad (9)$$

The minimization of this energy maximizes the cooperation.

Because all these distances yield the same dynamics of the system, it doesn't need to be specified exactly if the actor aim is, psychologically, the minimization of conflicts, the maximization of cooperation, or both, and in which proportion. However, this prevents us from comparing the energies of different systems (including the same actors with some propensities changed) until this is established. In our study we will stick to the original AB form of the distance (which minimizes conflicts).

3.3 Neutrality

The introduction of spin variables allows us to consider the possibility of neutrality by letting the spins to have also the value $\eta_i = 0$. In the case of bimodal coalitions, this is straightforward. In the case of n coalitions, the energy (7) has to be rewritten as

$$E = 2E_0 - \sum_{i>j}^{n} J_{ij}\delta(\eta_i, \eta_j)[1 - \delta(\eta_i\eta_j, 0)] , \qquad (10)$$

where the last factor accounts for the case when both i and j are neutral.

4 Application to real cases

4.1 The case of the Second World War

Axelrod and Bennett have applied their model of aggregation to explain the composition of the opposing alliances during the Second World War [2]. The actors are 17 European countries involved in the war. Country sizes are measured with a national capabilities index which combines six components of demographic, industrial and military power. Propensities are computed from 1936 data. The criteria used are: ethnic conflicts, religion, border disagreements, type of government and history of war. They are combined with equal weights.

After numerical minimization of the energy, two different minima were found. The absolute one corresponds to respectively Britain, France, Soviet Union, Czechoslovakia, Yugoslavia, Greece and Denmark in one coalition *versus* Germany, Italy, Poland, Romania, Hungary, Portugal, Finland, Latvia, Lithuania and Estonia in the other one. After the criteria of Axelrod and Bennett (who measure the alignment by whether a country was invaded by another country, or had war declared against it), this corresponds to the historical reality, with the exception of Poland, which is on the wrong side, and of Portugal, which was neutral. There exists another local minimum with Soviet Union, Yugoslavia and Greece *versus* all the others.

While Axelrod and Bennett exhibit this result as a validation of their model, they hardly comment a crucial assumption they made. They supposed that the 17 countries can be partitioned in only 2 coalitions. Even if this was the historical reality, this artificially added constraint does not fit to the principles of the model. The final configuration should be determined only by the actors' pairwise

interactions, *via* the minimization of the energy. Nothing restricts a priori the existence of more than 2 coalitions. A partition in two coalitions should be indeed a result of the model and a proof of its predictiveness.

4.2 Revisiting the Second World War case

We have redone the AB computation using the same data set for sizes and propensities (which is available on Internet [8]).

We first confirmed the AB results once the number of coalitions is restricted to 2. We then introduced the possibility of spin 0 in the hope of capturing the neutrality of Portugal while keeping the other conditions unchanged. The results stay unchanged with no country neutral.

We then allowed an *a priori* unlimited number of coalitions (from 1 up to $n = 17$). Exploring then the full energy landscape, we found that there exists one single minimum associated to 3 alliances. They are respectively Soviet Union and Greece *versus* Germany, Italy, Estonia and Latvia *versus* Britain, France, Czechoslovakia, Denmark, Yugoslavia, Poland, Romania, Hungary, Portugal, Finland and Lithuania. This minimum has an energy $E = -132.36$. It is much less than the energies of the two AB configurations which are respectively -94.23 and -91.06.

We also tried to find a 2 coalition configuration imposing geographical constraints, but the result stays a three alliance configuration. This shows that, in fact, the real prediction of the AB model, using the same propensities, is rather far from the historical reality.

4.3 The Unix case

Axelrod *et al.* applied the AB model of aggregation to explain also the formation of standard setting alliances, like for the Unix operating system [4]. The actors are 9 companies involved in the development of Unix (AT&T, Sun, Apollo, DEC, HP, Intergraph, SGI, IBM and Prime). Sizes are given by the firms' share in the technical workstation market or by expert estimates (for AT&T).

If a firm i belongs to alliance L, its utility (the satisfaction of the economic agent, given by its profit) is expressed by

$$U_i(L) = \sum_{j \in L} s_j - \left[\alpha \sum_{j \in L'} s_j + (\alpha + \beta) \sum_{j \in L''} s_j \right] , \quad (11)$$

where s_j is the size of firm j, and L' and L'' form a partition of alliance L into distant and close rivals of i ($L = L' \cup L''$ and $L' \cap L'' = \emptyset$). The parameters α and β are positive. The identification of close and distant rivals is done from the degree of specialization of the firms in the production of Unix-based workstations.

We may rewrite the utility as

$$U_i(L) = \sum_{j \in L} s_j p_{ij} = \sum_{j=1}^{n} (1 - d_{ij}) s_j p_{ij} , \quad (12)$$

where the last expression gives the utility of i without having to specify its alliance. This leads to the propensities $p_{ij} = 1 - \alpha$, if i and j are distant rivals, and $p_{ij} = 1 - (\alpha + \beta)$, if i and j are close rivals.

The energy (3) equals

$$E = 2E_0 - \frac{1}{2} \sum_{i=1}^{n} s_i U_i , \quad (13)$$

so a minimization of the energy yields a weighted maximization of the utilities.

For the choice of parameters $\alpha = \beta = 1$ (and in all cases for which $0.8 \leq \alpha \leq 1.5$, $0.7 \leq \beta \leq 1.5$), Axelrod *et al.* found 2 minimums of the energy with the same value. One configuration is Sun, DEC and HP *versus* AT&T, Apollo, Intergraph, SGI, Prime and IBM. The other one is Sun, AT&T, Prime and IBM *versus* DEC, HP, Apollo, Intergraph and SGI. The latter configuration corresponds to Unix International *vs.* Open Software Foundation, and only IBM is incorrectly assigned.

Axelrod *et al.* advocate this result in favor of the effectiveness of their methodology. However, they have again imposed the artificial constraint of allowing only a maximum of 2 coalitions. They motivate this choice by the fact that "the positive externality created by standardization declines as the number of standards increases and thereby reduces the principal advantage of setting standards, which is a larger post-standardization market" ([4], p. 1498).

But this condition is in fact included in the formula of the utility $U_i(L)$, which grows linearly with the total size of coalition L. Therefore, the aggregation of firms into a small number of alliances should be only the result of the energy minimization. If the utility grows faster than linearly with the coalition size (which may be the case in reality), and the linear approximation is not good enough, then even if we impose a maximum of 2 coalitions the result would be wrong, because of the discrepancy between the real and the modeled utility.

4.4 Revisiting the Unix case

We checked the above model with no conditions imposed on the coalition number. For the case $\alpha = \beta = 1$ there exist 150 different minimums of the energy, with an average of 6.57 coalitions per configuration. This is definitely a bad choice of parameters because all the propensities are negative or 0, so there is little incentive for aggregation.

The condition for the beginning of aggregation is $\alpha < 1$. We sampled the interval $0 \leq \alpha \leq 0.9$, $0 \leq \beta \leq 2$, with a step of 0.1. For $\alpha + \beta < 1$, all firms form a single block (all propensities are positive). Configurations with 2 coalitions appear in an interval given roughly by $1 - \alpha < \beta < 2(1 - \alpha)$.

There are 14 types of configurations of 2 coalitions. We ranked their importance from the number of pairs (α, β) for which they are realized, weighted with the size of their basin of attraction. The most preferred configurations are (i) Sun, AT&T and IBM *versus* the others (29.6%), (ii) AT&T and Apollo *versus* the others (28.4%), (iii) IBM, DEC and Apollo *versus* the others (12.5%), the rest having less than 10% each.

The "best" configuration predicted by Axelrod *et al.* is not realized at all, while the other configuration they predicted has rank 4 (5.5%). The real empirical configuration Sun, AT&T and Prime *versus* the others has rank 9 (2.7%) and doesn't have a basin of attraction greater than 6% for any combination of parameters.

Again, as for the Second World War, the prediction of the non constrained AB model, using the same propensities, doesn't fit the empirical reality.

5 A new application: the case of Yugoslavia

We have studied a new problem, the fragmentation of the former Yugoslavia. The actors are its 8 administrative entities (provinces or republics): Serbia, Croatia, Bosnia, Slovenia, Macedonia, Vojvodina, Kosovo and Montenegro. Here a coalition means a federation of entities, or an independent state if it has only one member.

In the initial configuration all the actors are in the same coalition – the former Yugoslavian federation. The system is then left to evolve in the direction of the greatest gradient of energy down to the minimum which should correspond to the stable configuration.

To implement our model we needed first to evaluate all the propensities among the set of the 8 entities. The ethnic group diversity [6] of the whole set is a major ingredient which we considered in evaluating those propensities. We also took into account differences in religion and language. Entity sizes are taken proportional to population sizes.

We used the 1981 census results [9,6]. We considered eight major ethnic groups: Serbs, Croats, Muslims, Slovenes, Macedonians, Montenegrins, Albanians and Hungarians. We neglected in our study the influence of other ethnic groups. They accounted for less than 1% each of the total population of Yugoslavia in 1981. We also neglected the 5.4% of the population which label themselves Yugoslavian. We assumed this later group to be perfectly tolerant of the others (zero propensity).

Due to lack of accurate data for all the entities, we considered all the Serbs, Macedonians and Montenegrins to be Orthodox Christians; all the Croats, Slovenes and Hungarian to be Catholic Christians; and all the Muslims and Albanians to be Muslim. For 1999, there exist differences up to 25% between the figures for nationality and religion, but in most cases they are much less [10]. We classified the ethnic groups, with regard to their language, as Serbo-Croats (Serbs, Croats, Muslims and Montenegrins), other Slavs (Macedonians and Slovenes) and non Slavs (Albanians and Hungarians) [6].

The propensities between pairs of entities are computed as follows:

$$p_{ij} = \sum_{k,l}^{8} q_{ik} q_{jl} w_{kl} \ , \qquad (14)$$

where q_{ik} represents the percentage of ethnic group k in entity i and w_{kl} represents the pairwise propensity between ethnic groups k and l.

For $k = l$, $w_{kk} = +1$. For $k \neq l$, the w_{kl}'s are computed as the sum of 2 terms. One stands for religion and the other for language: $w_{kl} = \omega_{\text{religion}}(k,l) + \omega_{\text{language}}(k,l)$.

We used the hypothesis that Christians are more tolerant of other Christian religion members than for Muslims. We also assumed that the Serbo-Croats are more tolerant of other Slavs than of non Slavs.

For religion, the factor ω_{religion} is positive and equals $+\omega_1$ for pairs of ethnic group with the same religion. It is negative and equals $-\omega_2$ for pairs of Catholic Christian and Orthodox Christian ethnic groups. For pairs of Christian and Muslim groups, the factor is $-\omega_3$.

For language, the factor ω_{language} is $+\omega_4$ in the case of two Serbo-Croatian speaking groups. For pairs of two different Slav groups, the factor is $-\omega_5$. For pairs that include at least a non Slavic language, the factor is $-\omega_6$. All the ω_i's are positive.

The graduation of tolerance previously described yields the following conditions: $\omega_2 < \omega_3$ and $\omega_5 < \omega_6$. We also have the condition $\omega_1 + \omega_4 < 1$ to prevent a pairwise propensity between 2 different ethnic groups to be greater than the propensity within the same group, which is the reference factor for other propensities.

The parameters ω_i are unknown. We varied those parameters in the domain $0 < \omega_{1,4} < 0.5$; $0 < \omega_{3,6} < 1$; $\omega_2 < \omega_3$; $\omega_5 < \omega_6$, with a step of 0.05 and checked the results predicted by the minimization of the energy. There are 28 resulting configurations (from a total of 4140 possibilities).

All these configurations respect the geographical connectivity. We ranked them from the number of cases they are realized, weighted with the relative size of their basin of attraction in each case. Only three configurations appear in more than 10% of cases each and 11 other appear in more than 1% of cases each.

The main three configurations are: (i) A federation including Serbia, Croatia, Bosnia, Montenegro and Vojvodina, with the other entities being independent, is obtained in 42.4% of cases. (ii) In 12.1% of cases the result is Serbia, Montenegro and Vojvodina, and the others independent. (iii) In 10.9% of cases, only Serbia and Vojvodina stay together.

The above results yield the real configuration which resulted from the fragmentation of Yugoslavia for the second largest set of parameters. We considered Kosovo practically separated from Serbia because of its special situation after the 1999 war, under the control of NATO peacekeepers.

For this final configuration, in 31% of cases (for example for a choice of parameters ω_i like (0.2, 0.5, 0.6, 0.1, 0.3, 0.5)), the order of fragmentation

is the real one: Croatia and Slovenia - June 1991, Macedonia - September 1991, Bosnia - April 1992, with the general exception of Kosovo. Our model predicts its splitting from Yugoslavia on the first or the third step, due to its mostly Albanian population. Within our model and the G model we might say that Kosovo was artificially kept inside Serbia using an external field. The field was then destroyed by the NATO bombing.

6 Conclusion

The introduction of analogies inspired from spin glass models into the study of social systems makes possible the prediction of the dynamics of macroscopic alliances formation within a given system of actors. While pairwise interactions are clearly instrumental in this approach, there is no scientific method to date to select the factors to be accounted for in their evaluation.

We have shown in particular that previous studies were not consistent with their own principles. Using the propensities and sizes computed from their methodology and then computing the resulting configurations, following strictly and solely the principle of the minimum energy, we have shown that the results don't fit any more to reality. Nevertheless we have also shown that there exist some parameter ranges which do yield the real situation.

We have also emphasized that analogies with physics should not mean a straight mapping. A major difference here is to consider the number of alliances to be a free internal parameter of the system. In physics it is predetermined.

In conclusion our approach validates the feasibility of modeling strategic international behavior, but at the same time it demonstrates also the dangers of taking it too simplistically. Within our model, we have also reported configurations which don't fit to reality. At this stage, this shows that more work is necessary to single out a feasible scheme for the evaluation of parameters.

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