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A Landscape Theory of Aggregation

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Aggregation means the organization of elements of a system into patterns that tend to put highly compatible elements together and less compatible elements apart. Landscape theory predicts how aggregation will lead to alignments among actors (such as nations), whose leaders are myopic in their assessments and incremental in their actions. The predicted configurations are based upon the attempts of actors to minimize their frustration based upon their pairwise propensities to align with some actors and oppose others. These attempts lead to a local minimum in the energy landscape of the entire system. The theory is supported by the results of two cases: the alignment of seventeen European nations in the Second World War and membership in competing alliances of nine computer companies to set standards for Unix computer operating systems. The theory has potential for application to coalitions of political parties in parliaments, social networks, social cleavages in democracies and organizational structures.

This article presents a formal theory of aggregation, called landscape theory, and provides two tests of the theory. 'Aggregation' means the organization of elements of a system in patterns that tend to put highly compatible elements together and less compatible elements apart. Landscape theory uses abstract concepts from the physical sciences and biology that have proved useful in studying the dynamics of complex systems. These concepts provide a way of thinking about the many possible ways in which elements of a system can fit together, predicting which configurations are most likely to occur, how much dissatisfaction with the outcome is inevitable and how the system will respond to changes in the relationship between the elements. As applied to political, economic and social problems, landscape theory can be used to analyse a wide variety of aggregation problems that have previously been considered in isolation:

(1) international alignments,
(2) alliances of business firms to set standards,
(3) coalitions of political parties in parliaments,
(4) social networks,
(5) social cleavages in democracies, and
(6) organizational structures.

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In order to be useful, a theory of aggregation should have the following properties.

(a) The theory should provide a coherent explanation of why some particular aggregations (alliances, coalitions, organizational structures, etc.) form in a given system, and not others.
(b) The theory should illuminate the dynamics of aggregation to provide a deeper understanding of the actual process involved as well as the end result.
(c) The theory should be general enough to apply to many domains of politics and society.
(d) The theory should be simple enough to illuminate some fundamental aspects of aggregation.
(e) The theory should be capable of being operationalized so that its predictions can be tested.

This article seeks to demonstrate that the landscape theory of aggregation offers excellent promise of fulfilling all five of these conditions. In particular, this article provides the first empirical test of a theory of alignment in international politics. It does so by providing a new theoretical approach to aggregation dynamics and by being practical about measurement. The significance of landscape theory is that it can provide a deeper understanding of a wide variety of important aggregation processes in politics, economics and society. How the elements of a system fit together has important implications for such vital issues as the balance of power in international politics, the way in which competing businesses can agree to set standards for their products, the construction of ruling coalitions among parties in parliamentary democracies and the ways political parties appeal to voters in a society with overlapping and cross-cutting cleavages.

By using a common set of concepts to explain a variety of distinct subjects, the current understanding of each subject can be used to help illuminate the others. Moreover, by using a common theory, such as landscape theory, one might reach a deeper understanding of how the aggregation process in each of these domains is similar to the others and how each is different from the others. In addition to purely scientific significance, landscape theory can be used as a guide to policy. For example, by providing a coherent explanation of which international alignments are likely to form, it can suggest where leverage can most efficiently be applied to move from one configuration to another. As another example, the theory could suggest which domestic political coalitions are inherently unstable and which would become stable if critical subgroups could be induced to make minor changes.

The next section formally presents landscape theory, followed by a section on how the concept of an abstract landscape has been used in the physical and natural sciences. Then two operationalizations and tests of the theory are provided, one from international politics and the other from economics. The penultimate section shows how the theory could be applied to four other domains as well. The final section considers how the foundations of landscape theory can be made more rigorous.

LANDSCAPE THEORY

This section explains the formal aspects of the theory, shows how the concepts of the approach may help to illuminate an aggregation process and enumerates the predictions that can be derived from the theory.

Landscape theory predicts how actors will form alignments. To help keep the terminology as simple as possible, the language of international alignments will be used. The theory makes two basic assumptions, both drawn from the recognition that it is difficult for a national leadership to assess the value of each potential alignment. The first assumption is that a nation is myopic in its assessments. In other words, a national leadership evaluates how well it gets along with any other nation independent of all the other members in the system. By making only pairwise evaluations, the national leadership avoids the difficult problem of assessing all combinations of nations at once.

The second basic assumption of landscape theory is that adjustments to alignments take place by incremental movement of individual nations. This rules out the possibility that a coalition will form within an alignment and then switch allegiance as a block. This strong assumption is appropriate when information regarding payoffs is uncertain, resulting in causal ambiguity between alignment actions and payoffs, and a consequent increase in negotiation costs and a reduction in the ability of nations to use side payments to arrive at an optimal solution.

Landscape theory begins with a set of n *actors* (for example, nations). The *size* of a nation, $s_i > 0$, is a reflection of the importance of that country to others. Size might be measured by demographic, industrial or military factors, or a combination of these, depending on what is taken to be important in a particular application.

The key premise of landscape theory is that each pair of nations, i and j, has a *propensity*, p_{ij}, to work together. The propensity number is positive and large if the two nations get along well together and negative if they have many sources of potential conflict. Put another way, propensity is a measure of how willing the two nations are to be in the same coalition together. If one country has a source of conflict with another (such as a border dispute), then the second country typically has the same source of conflict with the first. Thus the theory assumes that propensity is symmetric, so that $p_{ij} = p_{ji}$.

A *configuration* is a partition of the nations, that is a placement of each nation into one and only one grouping. An example is the post-war situation in which the non-neutral nations of Europe were divided between NATO and the Warsaw Pact. A specific configuration, X, determines the *distance*, d_{ij}, between any two countries, i and j. In the simplest version of the theory all countries are assumed to be in one of two possible groupings, so we can let distance be 0 if the two countries are in the same grouping, and 1 if the two countries are in different groupings. In other situations, other measures of distance in a configuration will be appropriate.[1]

Using distance and propensity it is now possible to define a measure of *frustration*: how poorly or well a given configuration satisfies the propensities of a given country to be near or far from each other country. A nation, i, wants to switch sides if the frustration is less on the other side. The frustration of a country, i, in a configuration, X, is just

$$F_i(X) = \sum_{j \neq i} s_j p_{ij} d_{ij}(X) \tag{1}$$

where s_j is the size of j, p_{ij} is the propensity of i to be close to j, and $d_{ij}(X)$ is the distance from i to j in configuration X. The summation is taken over all countries except $j = i$. Note that the definition of frustration weights propensities to work with or against another country by the size of the other country. This takes account of the fact that a source of conflict with a small country is not as important for determining alignments as an equivalent source of conflict with a large country. Notice that a country's frustration will be minimized if it is:

(a) in the same alliance as those countries with which it has a positive propensity to align, since otherwise $p_{ij} > 0$ and $d_{ij}(X) > 0$, and
(b) in a different alliance from those countries with which it has a negative propensity to align, since this would make $d_{ij}(X) > 0$ when $p_{ij} < 0$.

Note also that the myopic assumption is built into the definition of frustration since a given country's evaluation of a configuration depends on its pairwise propensities with each of the other nations and does not take into account any higher order interactions among groups of countries.

The next step is to define the *energy* of an entire configuration, X, as the weighted sum of the frustrations of each nation in that configuration, where the weights are just the sizes of the nations. This gives the energy of a configuration as:

$$E(X) = \sum_{i} s_i F_i(X) \tag{2}$$

Substituting the definition of frustration into this equation allows the calculation of the energy of a configuration in terms of size of the countries, their propensities to work together, and their distances in a particular configuration:

$$E(X) = \sum_{i,j} s_i s_j p_{ij} d_{ij}(X) \tag{3}$$

The summation is over all ordered pairs of distinct countries.

The formula for the energy of a configuration captures the idea that energy is lower (and the configuration is better) when nations that want to work

[1] For example, the distance between two jobs in a hierarchical organizational structure can be regarded as the number of layers of the organization that have to be ascended to reach a common boss. See p. 232 below.

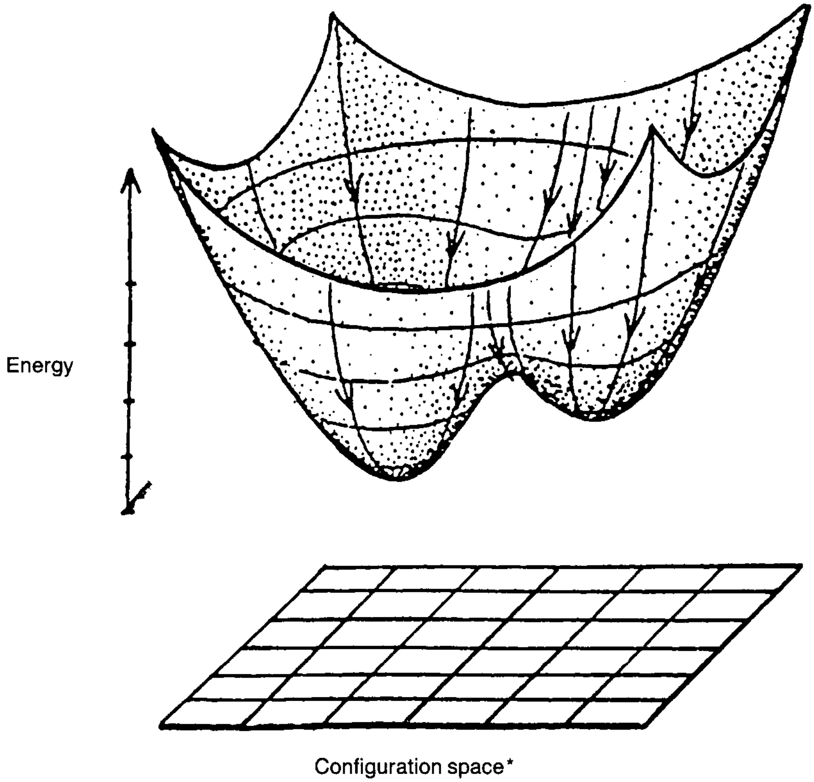

Fig. 1. A landscape with two local optima
Note: Adapted from Abraham and Shaw, *Dynamics*, Part 2; used with the permission of Ariel Press.
*The configuration space is an n-dimensional binary hypercube. The hypercube has one dimension for each firm indicating which of the two possible alliances that firm is in.

together are in the same grouping, and those that want to work against each other are in different groupings. Size plays a role because having a proper relationship with a large country is more important than having a proper relationship with a small country.

Once energy is defined, the abstraction begins to pay off. Given the energy of each configuration it is possible to construct an energy *landscape*. The landscape is simply a graph which has a point for each possible configuration, and a height above this point for the energy of that configuration. Figure 1 shows an example of a landscape where each point in the plane at the bottom of the figure indicates a specific configuration and the surface above the plane represents the energy of that configuration. Adjacent points on the landscape are those that differ in the alignment of a single nation. The landscape has a dimension for each country indicating which alignment it is in. Since it is not possible to draw a large-dimensional hypercube, in Figure 1 we have provided a conceptual (two dimensional) surface instead.

The incremental assumption allows predictions to be made about the dynamics of the system. The incremental assumption provides that only one nation at a time will change sides and will do so in a manner to lower its own frustration. Given that the energy of a configuration is the weighted sum of the frustrations of individual nations, when one nation lowers its frustration, the energy of the entire system is lowered.[2] The resulting reduction in energy means that wherever the system starts on the energy landscape, it will run 'downhill' to an adjacent configuration that has lower energy. Thus the changes in alignment patterns will stop only when a configuration is reached that is a local minimum. For example, in Figure 1 there are two local minima and thus two potentially stable configurations. Stability here means that the configuration (that is, alignment pattern) does not change any further under existing conditions.

Which stable configuration will occur depends on where the system starts. For example, in Figure 1 any configuration on the left-hand side of the figure tends to move to the low point on the left-hand side, which happens to be the global minimum. All the configurations that would lead to this minimum can be thought of as the *basin of attraction* of that minimum.

Specifically, the predictions of landscape theory are:

(1) From a given starting configuration, the configuration will change according to the principle of downward movement to an adjacent configuration.
(2) Consequently, the only stable configurations are those that are at a local minimum in the landscape.
(3) With symmetric propensities there can be no cycles of configurations (such as moving from X to Y to Z and then back to X).[3]

An interesting implication of this approach is that the equilibrium reached need not be a global optimum. For example, in Figure 1 there are two local minima into which the system can settle. The local minimum on the right is not as good at satisfying the propensities of the countries as is the one on the left. Therefore, if the system happened to start on the far right, it would settle down to a local minimum that was not a global minimum.

[2] The symmetry of propensities guarantees that if one nation reduces its frustration by switching sides then the energy for the whole system will be reduced. Here is the proof. Without loss of generality, let $X = A'$ versus B where $A' = A \cup \{k\}$, and let $Y = A$ versus B' where $B' = B \cup \{k\}$. To shorten the notation let $K = \{k\}$ and $r_{ij} = s_i s_j p_{ij}$. $E(X) = \Sigma_{A'}\Sigma_B r_{ij} + \Sigma_B \Sigma_{A'} r_{ij}$ since $d_{ij}(X) = 0$ for $i \epsilon A'$, $j \epsilon A'$ or $i \epsilon B$, $j \epsilon B$; and $d_{ij}(X) = 1$ for $i \epsilon A$, $j \epsilon B'$ or $i \epsilon B$, $j \epsilon A'$. Likewise $E(Y) = \Sigma_A \Sigma_{B'} r_{ij} + \Sigma_{B'} \Sigma_A r_{ij}$. So $E(X) - E(Y) = \Sigma_{A'}\Sigma_B r_{ij} - \Sigma_A \Sigma_{B'} r_{ij} + \Sigma_B \Sigma_{A'} r_{ij} - \Sigma_{B'}\Sigma_A r_{ij} = \Sigma_K \Sigma_{B'} r_{ij} - \Sigma_A \Sigma_K r_{ij} + \Sigma_B \Sigma_K r_{ij} - \Sigma_K \Sigma_A r_{ij}$ since $\Sigma_{A'}\Sigma_B r_{ij} = \Sigma_A \Sigma_B r_{ij} + \Sigma_K \Sigma_B r_{ij}$. But $\Sigma_K \Sigma_B r_{ij} = \Sigma_B \Sigma_K r_{ij}$ and $\Sigma_A \Sigma_K r_{ij} = \Sigma_K \Sigma_A r_{ij}$ since $p_{ij} = p_{ji}$. So $E(X) - E(Y) = 2(\Sigma_K \Sigma_{B'} r_{ij} - \Sigma_K \Sigma_{A'} r_{ij}) = 2(s_k \Sigma_B s_j p_{kj} - s_k \Sigma_A s_j p_{kj}) = 2s_k(F_k(X) - F_k(Y))$, since $d_{kj}(X) = 0$ for $j \epsilon A$, $d_{kj}(X) = 1$ for $j \epsilon B$, $d_{kj}(Y) = 0$ for $j \epsilon B$, and $d_{kj}(Y) = 1$ for $j \epsilon A$.But $s_k > 0$. So for adjacent configurations, X and Y, differing only by nation k, if $F_k(X) - F_k(Y) > 0$ then $E(X) - E(Y) > 0$.

[3] Since every allowable change lowers the energy of the system, the system can never return to a previous configuration.

Another implication is that there may not be *any* configuration that completely satisfies everyone. Even for a configuration that is the global optimum, most or even all nations may be somewhat *frustrated* in the sense that some 'friends' will be in the opposite grouping and/or some 'enemies' will be in the same grouping. For example, if there are three nations that mutually dislike each other (such as Israel, Syria and Iraq), then any possible bipolar configuration will leave someone frustrated.

A further implication is that the local optimum into which the system settles can depend on the history of the system. Early history, which might be in part the consequence of small events or even chance circumstances, can determine which outcome prevails. Thus the outcome may be in part the consequence of a 'frozen accident' just as the QWERTY keyboard is.[4] Once the system settles into a basin, it may be difficult to leave it. Moreover, if there is more than one local optimum, the one that the system settles into may not be the one with the lowest energy or the least total frustration.[5]

The theory is relevant to policy in that it illuminates where minor changes in the initial configuration can lead to major changes in the final configuration. If one begins near the boundary of two basins of attraction, then a small movement at the start can lead to large changes in the final outcome. In addition, the height of the 'pass' between valleys gives the magnitude of the 'energy barrier' separating one basin of attraction from another and therefore measures how difficult it would be to move the system from one local optimum to another.

To summarize: landscape theory begins with sizes and pairwise propensities that are used to calculate the energy of each possible configuration and then uses the resulting landscape to make predictions about the dynamics of the system.

ABSTRACT LANDSCAPES IN THE PHYSICAL AND NATURAL SCIENCES

The idea of an abstract landscape has been widely used in the physical and natural sciences to characterize the dynamics of systems. It was originally developed to study potential energy in physical systems and had its first rigorous development in the context of Hamiltonian systems.[6] Biologists have independently developed landscapes to characterize evolutionary movement in an

[4] Paul David, 'Clio and the Economics of QWERTY', *American Economics Review Proceedings*, 75 (1985), 332–7.

[5] Brian W. Arthur, 'Self-Reinforcing Mechanisms in Economics', in P. W. Anderson, K. J. Arrow and D. Pines, eds, *The Economy as an Evolving Complex System* (Reading, Calif.: Addison-Wesley, 1988).

[6] See Vladimir Igorevich Arnol'd, *Mathematical Methods of Classical Mechanics* (New York: Springer, 1978 (translated from the Russian)); Ralph Abraham and Christopher Shaw, *Dynamics – The Geometry of Behavior* (Santa Cruz, Calif.: Aerial Press, 1983); Gregoire Nicolis and Ilya Prigogine, *Exploring Complexity, An Introduction* (New York: Freeman, 1989).

abstract 'fitness landscape' of genes.[7] More recently, energy landscapes have been used in artificial intelligence to characterize the dynamics of complex systems such as neural networks.[8]

The landscape theory of aggregation uses concepts that have been developed most thoroughly by physicists and chemists under the label of 'frustrated systems' or 'spin glasses'.[9] A simple example is the Ising model that studies how magnets on a plane can attain various alignments based upon their mutual attraction or repulsion.[10] Another common application is the stability of alignment of chemical bonds.[11] Landscape theory borrows four key ideas from these settings: a set of elements have pairwise propensities to align with each other in specific ways, each possible configuration has an 'energy', the resulting landscape shows all possible configurations, and the dynamics of the system can be predicted from the initial conditions and the shape of the landscape. Landscape theory adds the possibility of unequal sizes of units and allows operationalizations of propensities and distances that are appropriate to specific social science applications. Unlike spin glass theory, landscape theory does not assume that the propensities are randomly determined. Recently, landscapes have been used to explore fundamental properties of dynamic systems. In particular, catastrophe theory studies how basins of attraction can be formed or disappear due to changes in the shape of the landscape.[12]

Landscapes have not been widely used in game theory, but some of the predictions of landscape theory can be stated in game theoretic terms. Landscape theory says that the stable configurations are exactly those that are in Nash equilibrium. What landscape theory adds to game theory is a way of characterizing all possible configurations and the dynamics among them. In particular, the idea of descent from less satisfactory patterns to more satisfactory patterns helps one characterize the entire range of possibilities in a manner

[7] Sewell Wright, 'The Roles of Mutation, Inbreeding, Crossbreeding and Selection in Evolution', *Proceedings of the International Congress of Genetics*, 1 (1932), 356–66; Stuart A. Kauffman, 'Adaptation of Rugged Fitness Landscapes', in Daniel L. Stein, ed., *Lectures on the Sciences of Complexity*, vol. I (Redwood City, Calif.: Addison-Wesley, 1989).

[8] See John J. Hopfield, 'Neutral Networks and Physical Systems with Emergent Computational Abilities', *Proceedings of the National Academy of Sciences (USA)*, 79 (1982), 2554–8. In biology and artificial intelligence, the polarity of the landscape is reversed so that the improvement is thought of as hill-climbing rather than descent into valleys.

[9] David Pines, ed., *Emerging Synthesis in Science* (Santa Fe, N. Mex.: Santa Fe Institute, 1985); Debashish Chowdhury, *Spin Glasses and Other Frustrated Systems* (Princeton, NJ: Princeton University Press, 1986); Marc Mezard, Giorgio Parisi and Miguel Angel Virasoro, *Spin Glass Theory and Beyond* (Singapore: World Scientific, 1987).

[10] W. Weidlick, 'Statistical Description of Polarization Phenomena in Society', *British Journal of Mathematical Statistical Psychology*, 24 (1971), 251–66; Daniel L. Stein, 'Disordered Systems: Mostly Spin Glasses', in Daniel L. Stein, ed., *Lectures on the Sciences of Complexity*, vol.1 (Redwood City, Calif.: Addison-Wesley, 1989), pp. 301–53.

[11] Nicolis and Prigogine, *Exploring Complexity, An Introduction.*

[12] Rene Thom, *Structural Stability and Morphogenesis* (Reading, Mass.: W. A. Benjamin, 1975 (translated from French)); E. C. Zeeman, *Catastrophe Theory* (Reading, Mass.: Addison-Wesley, 1977).

that is sometimes obscure in game theoretic treatments of *n*-person settings. Moreover, the idea of descent need not be justified by an appeal to far-sighted rational decision making, but can easily be the result of a process in which each actor responds to the current situation in a short-sighted attempt to achieve local improvement.

Before turning to some applications of the landscape theory of aggregation, it should be pointed out that aggregation has been studied without landscapes as a descriptive problem in statistics. In the social sciences, the most commonly used descriptive technique is cluster analysis.[13] Cluster analysis has been described as 'the art of finding groups in data',[14] and is used 'as a descriptive or exploratory tool, in contrast with statistical tests which are carried out for inferential or confirmatory purposes'.[15] Unlike landscape theory, however, cluster analysis is not based on a dynamic theory of behaviour and it cannot make predictions.[16]

PREDICTING THE ALIGNMENT OF THE SECOND WORLD WAR IN EUROPE

In international relations, aggregation is usually studied in the context of alliances. The dominant approach to explaining international alliances is that states form alliances primarily to resist aggression by other powerful states.[17] Based upon the realist paradigm, this balancing behaviour assumes an anarchic international system in which all states view each other as potential enemies. In landscape theory, this is equivalent to saying all propensities are equal and negative. Given all negative propensities, landscape theory would then predict

[13] Mark S. Aldenderfer and Roger K. Blashfield, *Cluster Analysis* (Beverly Hills, Calif.: Sage, 1984); Benjamin Duran and Patrick L. Odell, *Cluster Analysis* (Berlin: Springer-Verlag, 1974); Leonard Kaufman and Peter J. Rousseeuw, *Finding Groups in Data: An Introduction to Cluster Analysis* (New York: Wiley, 1990).

[14] Kaufman and Rousseeuw, *Finding Groups in Data*, p. 1.

[15] Kaufman and Rousseeuw, *Finding Groups in Data*, p. 37.

[16] Other techniques which measure how good particular configurations are according to specific static criteria based on pairwise relationships include blockmodelling for which see Wayne Baker, 'Three-Dimensional Blockmodels', *Journal of Mathematical Sociology*, 12 (1986), 191–223; for simplicial decomposition, see D. W. Hearn, S. Lawphongpanich, and J. A. Ventura, 'Finiteness in Restricted Simplicial Decomposition', *Operations Research Letters*, 4 (1985), 125–30; for correspondence and canonical analysis, see Stanley Wasserman, Katherine Faust and Joseph Galaskiewicz, Correspondence and Canonical Analysis of Relational Data', *Journal of Mathematical Sociology*, 11 (1989), 11–64, and for a variety of techniques based on factor analysis including smallest space analysis and non-linear mapping, see Brian Everitt, *Graphical Techniques for Multivariate Data* (London: Heineman Educational Books, 1978). There are also econometric techniques to analyse how variables in dynamic systems aggregate from nearly decomposable subsystems: see Herbert A. Simon and Albert Ando, 'Aggregation of Variables in Dynamic Systems', *Econometrica*, 29 (1961), 111–38; Herbert A. Simon and Yuma Iwasaki, 'Causal Ordering, Comparative Statics, and Near Decomposability', *Journal of Econometrics*, 39 (1988), 149–73; Finn Kydland, 'Hierarchical Decomposition in Linear Economic Models', *Management Science*, 21 (1975), 1029–39.

[17] Hans J. Morgenthau, *Politics Among Nations* (New York: Alfred A. Knopf, 1956); Kenneth N. Waltz, *Theory of International Politics* (Reading, Mass.: Addison-Wesley, 1979).

as stable any alignment where the two alliances are balanced in terms of size, as these configurations are at a local minimum of energy. If size is interpreted as power, the predictions of landscape theory under realist assumptions are precisely balance of power alliances.

Actually, when states make alignment choices they take into account more than just power. Walt develops neo-realism by showing that states balance against particular threats.[18] Snyder notes that states have some interests which affect their behaviour towards all other countries, such as the desire to be militarily secure, but also have specific conflicts and affinities with particular other states based upon ideological, ethnic, economic or prestige values.[19] These 'general interests' and 'particular interests' establish a 'tacit pattern of alignment' among states.[20] Combining these interests with the neo-realist paradigm, it can be argued that Snyder's 'conflicts and commonalities' contribute to the threat that states perceive from others. Liska goes so far as to suggest that ideology and historic biases may preclude 'rational' alignment choices.[21] In fact, it is not unusual for scholars to note that alliance choices depend upon both power and interest.[22]

Unfortunately, particular interests and affinities have not yet been integrated into a coherent model of alignments. Landscape theory offers a way to provide this integration by representing divergent interests in the single concept of propensity, which combines with the size (power) of states to determine outcomes.

Landscape theory also provides a way of overcoming a second limitation of some leading alliance studies.[23] These studies of alliance formation focus on the decisions of individual states and hence do not predict the overall pattern of alliance aggregation. Landscape theory predicts the overall configuration by explicitly taking into account sequences of state action in reducing frustration until a local minimum is reached.

Let us now turn to the operationalization and testing of landscape theory

[18] Stephen M. Walt, *The Origins of Alliances* (Ithaca, NY: Cornell University Press, 1987).

[19] Glenn H. Snyder, 'The Security Dilemma in Alliance Politics', *World Politics*, 36 (1984), 461–95.

[20] Snyder, 'The Security Dilemma in Alliance Politics', p. 464.

[21] George Liska, *Nations in Alliance* (Baltimore, Md.: Johns Hopkins University Press, 1962), p. 27.

[22] See Ole R. Holsti, Terence Hopmann and John D. Sullivan, *Unity and Disintegration in International Alliances: Comparative Studies* (New York: Wiley, 1973), pp. 263–7 for a listing of hypotheses on alliance formation that go beyond power; also see James D. Morrow, 'Social Choice and System Structure in World Politics', *World Politics*, 41 (1988), 75–97.

[23] For example, Michael F. Altfield and Bruce Bueno de Mesquita, 'Choosing Sides in War', *International Studies Quarterly*, 23 (1979), 87–112; Michael F. Altfield, 'The Decision to Ally: A Theory and Test', *Western Political Quarterly*, 37 (1984), 523–44; James D. Morrow, 'On the Theoretical Basis of a Measure of National Risk Attitudes', *International Studies Quarterly*, 31 (1987), 423–38; Stephen M. Walt, 'Testing Theories of Alliance Formation: The Case of Southwest Asia', *International Organization*, 42 (1988), 275–316; and *The Origins of Alliances*.

as it applies to international alignments. In any application, the operationalization and testing of landscape theory requires answers to four questions.

(1) Who are the actors?
(2) What are their sizes?
(3) What are the propensities between every pair of actors?
(4) What is the actual outcome?

The answers to these questions depend on the specific domain being investigated. The operationalization and testing of the theory for international alignments can be illustrated and tested with the example of Europe in the years preceding the Second World War. This case is an appropriate test of landscape theory even given the assumption that actors are limited to membership in one of two alignments. In times when war is likely, states tend to divide into two opposing groups, for, as Waltz notes, 'the game of power politics, if really played hard, presses the players into two rival camps, though so complicated is the business of making and maintaining alliances that the game may be played hard enough to produce that result only under the pressure of war'.[24] The object of the test is to predict the alignment of nations that actually occurred during the war. The actors are the seventeen European nations who were involved in major diplomatic action in the 1930s.[25] The size of each nation is measured with the national capabilities index of the Correlates of War project.[26] The national capabilities index combines six components of demographic, industrial and military power.

1 As noted previously, power is not the only factor that states consider when making alignment choices. However, while power has been explored as it affects alignment and conflict behaviour, we know of no existing typology of state interests which would allow us to create a measure of interest-based propensities. We have attempted to create such a typology here. We divide state interests *vis-à-vis* other states into ethnic, religious, territorial, ideological, economic and historical concerns. We believe that this typology captures the main sources of affinities and differences between states as they might impact on strategic calculations. More specifically, in each dyad in our population we measure

[24] Waltz, *Theory of International Politics*, p. 167.

[25] Specifically, the countries selected are the five major European powers (Britain, France, Germany, Italy and the Soviet Union) and the twelve countries which had a formal defence or neutrality pact with any of them. Turkey was not considered to be in Europe. Two European countries were excluded: Albania because it was not independent of Italy, and Belgium because it withdrew from its defence agreement with France in 1936. Information about which was allied with which was not used in the analysis. The sources of alliance data are J. David Singer and Melvin Small, 'Formal Alliances, 1815–1939', *Journal of Peace Research*, 3 (1966), 1–31 and Melvin Small and J. David Singer, 'Formal Alliances, 1815–1965: An Extension of the Basic Data', *Journal of Peace Research*, 6 (1969), 257–82.

[26] David J. Singer, Stuart Bremer and John Stuckey, 'Capability Distribution, Uncertainty and Major Power War, 1920–1965', in Bruce Russett, ed., *Peace, War, and Numbers* (Beverly Hills, Calif.: Sage, 1972).

the presence of ethnic conflict, the similarity of the religions of the populations, the existence of a border disagreement, the similarity of the types of governments and the existence of a recent history of wars between the states.[27] These five factors are combined with equal weights to provide a measure of the propensity of each pair of nations to work together.[28] Using the above methods of measuring size and propensity, the energy was then calculated for each of the 65,536 possible configurations.[29]

The behaviour being predicted is the alignment of each country in the Second World War. This is measured by whether a country was invaded by another country, or had war declared against it.[30] By this criterion the actual alignment of the Second World War in Europe was Britain, France, the Soviet Union, Czechoslovakia, Denmark, Greece, Poland and Yugoslavia vs. Germany, Italy, Hungary, Estonia, Finland, Latvia, Lithuania and Romania. Portugal, which had a defence agreement with Britain, was neutral.

Using the 1936 size data, the resulting landscape has two local minima, which can be called Configuration 1 and Configuration 2. These two configurations are shown in Table 1. They provide the specific predictions of what would happen when war came. The results are striking. Configuration 1 was almost the exact alignment of the Second World War, the exceptions being Poland and Portugal which were incorrectly placed on the German side. Configuration 2 is best characterized as a pro-vs.-anti Soviet alignment consisting of the Soviet Union, Greece and Yugoslavia against all the others.[31]

What is one to make of this? First of all, the result is statistically significant: the probability that one of only two predictions would have no more than

[27] Due to the limitations of available data, we have not been able to operationalize economic issues and the level of economic interdependence in all dyads. Hence, we have simply omitted this category when calculating propensity.

[28] With n countries, there are $n(n-1)/2$ pairwise propensities. For $n = 17$, there are 136 pairwise propensities. Propensities are estimated as follows: ethnic conflict, a border disagreement or a recent history of war between two nations counted as -1 each for their propensity. Similarity of religion was counted as $+1$ within categories (Catholic, Protestant, Orthodox, Muslim and Atheist), and -1 across major categories (Christian, Muslim, Atheist), all calculated according to proportions of each religion in each country. Similarity or difference of government type was considered for two countries with democratic, fascist or communist governments: $+1$ if they were the same type and -1 if they were of different types. The source for ethnic conflict, border disagreement, history of war, and government type is Hermann Kinder and Werner Hilgemann, *The Anchor Atlas of World History*, vol. II (New York: Anchor Press, 1978). Religion is given in the Correlates of War Project's Cultural Data Set for 1930 (version of 7/90 prepared by Phil Schaefer). Selecting equal weights for the five propensity factors is the least arbitrary way of combining them.

[29] This is $2^{17}/2$. Each country can be in one of two possible sides, but which side is listed first is arbitrary.

[30] For example, Britain declared war on Germany in 1939. Poland was first invaded by Germany and hence is counted as being aligned opposite to Germany. Hungary and Romania were allied with Germany and in 1941 assisted in the invasion of the Soviet Union.

[31] In Configuration 2, Greece and Yugoslavia join the Soviet Union largely to avoid aligning with Germany, with whom both have a history of war.

TABLE 1 *The Two Configurations Predicted for the Second World War in Europe**

	Configuration 1 Alignment 1	*Configuration 1* Alignment 2
Configuration 2 Alignment 1	Britain (7.45) France (5.32) Czechoslovakia (1.15) Denmark (0.20)	Germany (11.49) Italy (4.03) Poland (1.83) Romania (0.78) Hungary (0.45) Portugal (0.27) Finland (0.19) Latvia (0.13) Lithuania (0.10) Estonia (0.06)
Configuration 2 Alignment 2	Soviet Union (15.01) Yugoslavia (0.59) Greece (0.35)	(None)
Nearest empirical match†	Allies (and those invaded by Germany)	Axis (and those invaded by the Soviet Union

*The size is shown in parentheses, in terms of percentage of world capabilities. The predicitons are based upon 1936 data.
† In Configuration 1, only Poland and Portugal are wrong.

two mistakes among the seventeen countries predicted is less than one in 200.[32] In addition, Configuration 1 had a basin of attraction that was more than twice the size of the other local minimum (47,945 configurations vs. 17,591), and hence it would be more likely to occur from a random starting initial situation.[33] Thus the configuration with the larger of the two basins of attraction was just two countries removed (Poland and Portugal) from the actual alignment of the Second World War. This configuration also had the global minimum of energy. Even more important, this configuration correctly accounted for the alignments of all the large nations and almost all of the smaller ones as well. In all, it correctly accounted for 96 per cent of the total size of the countries, as measured by their national capabilities index of demographic, industrial and military power.

As history played out, the nations did not get into the smaller basin of attraction, the one whose minimum was essentially a pro-and-anti Soviet alignment. While such an outcome seems implausible given what we now know

[32] There are 154 configurations that are as accurate or more so than the configuration that had two mistakes among the seventeen predicted nations. Since two different predictions are made and there are $2^{17}/2 = 65{,}536$ configurations, the chance that one of them would be this good is $2 \times (154/65{,}536) = 0.0047$.

[33] Steepest descent in the energy landscape is used to calculate basin size.

happened, it probably did not look quite so implausible to the participants at the time.[34] The error in placing Poland on the German side in the globally optimum configuration is not a preposterous one. Poland's foreign policy was antagonistic to both its powerful neighbours, Germany and the Soviet Union. In fact, while Germany invaded Poland first, on 1 September 1939, the Soviets invaded just sixteen days later. The error of placing Portugal on the German side (when it actually stayed neutral with pro-British sympathies) could be attributable to inadequate measures of cultural and economic affinity.[35]

While Configuration 1 was quite close to what happened, an interesting alternative possibility is presented by Configuration 2 in which the Soviet Union aligned with Greece and Yugoslavia against everyone else (see Table 1). In both configurations, Greece and Yugoslavia join the Soviet Union largely to avoid aligning with Germany, with which both have a history of war. Likewise, in both configurations, Germany and the Soviet Union were on opposite sides. Almost everyone had reasons to avoid aligning with either Germany or the Soviet Union. The key difference is that the democracies and their friends aligned against one of these large antagonists in the first configuration and aligned against the other one in the second configuration.

The actual alignment of the Second World War has thus been predicted quite well as early as 1936 by landscape theory using a standard power measure and the propensity measure developed above. However, it is possible that the simpler 'realist' approach would do just as well. The realist approach assumes that all countries, or at least all major countries, fear each other. This can be operationalized in terms of the landscape theory by setting the pairwise propensities to be equal and negative, say -1. We tested the realist model and found that it did poorly. An analysis of the seventeen countries with all -1 propensities and the size measure from above found not two but 209 different stable configurations, none of which was as accurate as the landscape theory prediction. An analysis of the five Great Powers with -1 propensities found four possible stable configurations, of which none was the actual outcome of Britain, France and the Soviet Union aligned against Germany and Italy. It seems that without the additional information provided by knowing what specific ethnic, religious, territorial, ideological and historic issues existed between countries in 1936, a realist model does not have adequate information

[34] For example, as late as 1939 when the Soviet Union invaded Finland, there were some active voices in Britain and France calling for intervention against the Soviet Union, despite the growing consensus that Germany was the major threat. Had Germany not blocked access by invading Norway, such action against the Soviets would not have been out of the question. Incidentally, the main reason that Yugoslavia and Greece side with the Soviet Union in Configuration 2 is that they both have a war history with Germany, but no serious problems with the Soviet Union.

[35] The error of placing Poland on the anti-German side occurred because Poland disliked the Soviet Union even more than it disliked Germany. This in turn was largely due to the Soviet Union's greater size (national capabilities) in 1936. As discussed below, this error was eliminated by 1939 as Germany mobilized its strength faster than the Soviet Union did. Portugal, which was actually neutral, was incorrectly placed on the German side because that side was more favourable for Portugal's Catholic religious propensity.

to make useful predictions. The basic problem with the realist approach is that without enough information to distinguish various types of pairwise propensities to align, large numbers of different alignments are equally plausible.

It is also possible that a cluster analysis of the propensity matrix might have revealed the Second World War alignment. Although cluster analysis normally assumes that the objects being clustered have equal weight, to approximate the landscape analysis more closely, we created a dissimilarity matrix of propensities weighted by sizes. We clustered this matrix with a standard hierarchical agglomerative technique, using the unweighted pair-group average (UPGMA) method of computing cluster dissimilarities, which we believe to be most appropriate for our purposes.[36] The two-cluster solution found Greece and the Soviet Union against everyone else, similar to the second optimum found by landscape theory, but not close to what happened historically. When we clustered Great Powers only, the analysis similarly placed the Soviet Union on the opposite side to Britain, France, Germany and Italy.

Thus it seems that in a static analysis, landscape theory is superior to alternative methods of computing likely alignments. A further test can be provided by the observation that, as the Second World War approached, the relative sizes (that is, national capabilities) of the countries changed, due largely to the rapid growth of military expenditures, especially in Germany. An interesting exercise is to see how the landscape and the predictions change as these changes in national capabilities are entered into the calculations, bringing us closer to the time when war actually broke out.[37]

For 1937, the same two configurations appear as we saw for 1936, namely Configuration 1 which is the alignment of the Second World War (except for Poland and Portugal), and Configuration 2 which is the pro-and-anti Soviet alignment. In 1938, however, there is only one local minimum and it is Configuration 1 again. Configuration 2 is no longer a local minimum. This coincides with the growing consensus in Britain that co-ordination with the Soviet Union might become necessary despite the repugnance of communism. In 1939, there is again only one local minimum, and it is similar to Configuration 1, only now Poland has moved from the anti-Soviet side to the anti-German side. This coincides with the growing strength of Germany which made it much stronger than the Soviet Union by 1939.

In summary, the theory does very well in predicting the European alignment of the Second World War with data up to 1936, but does even better as later data are used. By 1938, the predictions are narrowed from two to one, and by 1939 the single prediction becomes accurate for all but one of the seventeen

[36] Kaufman and Rousseeuw, *Finding Groups in Data*, pp. 47–8.

[37] The only change in the factors that went into the propensities from 1936 to 1939 was that Romania switched from a democratic government to an authoritarian government in 1938. Thus the changes in the landscape from 1936 to 1939 were almost entirely due to changes in the national capabilities of the various countries as they mobilized for war.

countries.[38] The chance that the single prediction of 1939 would be correct for sixteen of seventeen countries is less than one in three thousand.[39] Moreover, the ways in which landscape theory's predictions converged on the unique historically correct outcome seem to mirror the changes that actually took place in the late 1930s in Europe as the nations mobilized for war.

It is remarkable that such a simple theory and such a parsimonious operationalization of its concepts can come up with a prediction that is very close to what actually happened. Almost as striking is that departures from what actually happened reflect tenable alternatives to the way history played out.

We are aware of only one other theoretical prediction of the alignments in the Second World War. This is the rational-choice theory of Altfeld and Bueno de Mesquita which predicts how nations will choose sides once a war is under way.[40] Unlike landscape theory, which uses alliance behaviour only to identify active states, the Altfeld and Bueno de Mesquita model uses alliances to identify the utilities of the states and bases its predictions about alignments in war on these alliances patterns. The data used by landscape theory (such as religious and ideological differences) are much further back in the causal chain of predicting wartime alignment than are alliance data. Moreover, the Altfeld and Bueno de Mesquita model predicts events only after the outbreak of the war (for example, avoiding having to predict that Germany and Poland are on opposite sides), whereas landscape theory uses data only from before the outbreak of war, even years before. Yet another difference is that the Altfeld and Bueno de Mesquita model assesses its predictions only for countries that entered the war within two months of the outbreak, whereas the landscape theory makes predictions for all diplomatically active countries. A major limitation of the Altfeld and Bueno de Mesquita model is that it requires information about the actual wartime alignments to make any predictions since it needs this information to estimate the relative impact of the components of the expected utility equations. On the other hand, the Altfeld and Bueno de Mesquita model is superior in allowing for neutrality and in being applicable with only small modifications to wars over a long time period (1816–1965). In terms of results, the Altfeld and Bueno de Mesquita model failed to predict that Britain and France would enter the war against Germany and instead predicted that both would remain neutral. The landscape model predicted Britain and France correctly, as well as other countries that did not become involved in the conflict for several years.

Given the success of landscape theory in predicting all of the major powers, and almost all of the minor ones as well, we next applied landscape theory to the fluid situation of Europe in 1990 to see what would be predicted after

[38] Note that six of these countries were not destined to enter the war on either side for another year or two. In 1940 Hungary and Romania allied with Germany, and Denmark and Greece were invaded. In 1941, Yugoslavia and the Soviet Union were invaded.

[39] Since there are 65,536 different configurations, and only eighteen of them are off by zero or one country, the probability of a result this good happening by chance is 18/65,536 = 0.00027.

[40] Altfeld and Bueno de Mesquita, 'Choosing Sides in War'.

the Soviet Union ceased to impose its will on eastern Europe. The analysis used the nineteen European countries that were members of NATO or the Warsaw Pact in 1989, taking account of the unification of Germany, but not the subsequent disintegration of the Soviet Union. The operationalization used the same size measure as before. There are two changes in the operationalizations of propensities, however. First, because virtually all European governments are or aspire to be market-oriented democracies, ideology was dropped as a factor contributing to propensity. Secondly, economic relations were included as a factor in propensity, measured by mutual membership in the Common Market.[41] Starting at the 1989 (non-optimum) East–West alignment, landscape theory made the single prediction that the Soviet Union would be deserted by all of its former European allies except Bulgaria. Events prior to the collapse of the Soviet Union suggest that this was indeed what was taking place. In 1991 Poland, Czechoslovakia and Hungary sought a formal relationship with NATO, and NATO invited them to join a new North Atlantic Co-operation Council.[42] Only Romania has failed to act in the predicted manner before the break-up of the Soviet Union. (The probability that only one error would occur by chance with this many countries is less than one in a thousand.) In terms of size, the predictions correctly accounted for 97 per cent of the national capabilities of the system. In sum, the landscape theory correctly predicted that the break-up of the Warsaw Pact would result in most of the Soviet Union's allies seeking to join the Western alignment and none of the NATO members seeking to leave. While this may not be surprising, it does show that a theory that worked for the 1930s can also work for the 1990s.

PREDICTING THE ALLIANCES OF UNIX COMPUTER STANDARDS

A theory gains both usefulness and credibility when it can be shown to apply to several domains that were previously regarded as completely different. In this spirit, we provide a second domain of application, namely the formation of alliances among business firms to set standards for their products. For complete details, see Axelrod *et al.*[43] This section provides just the essentials from that paper.

[41] Thus mutual membership in the EEC added one point to the propensities of a pair of such countries. Because of limited data availability from the former Eastern bloc countries, a more precise measure of economic interdependence is unavailable. War history was based on the Second World War; Italy was considered to have a war history with no one since it fought on both sides. An additional source for coding ethnic conflicts is Stephen F. Larrabee, 'Long Memories and Short Fuses, Change and Instability in the Balkans', *International Security*, 15 (1990/91), 58–91. Size data was available as of 1985. To simplify the calculations Benelux was treated as one country and Spain/Portugal as another.

[42] *New York Times*, 11 November 1991 and 11 January 1992.

[43] Robert Axelrod, Will Mitchell, Robert E. Thomas, D. Scott Bennett and Erhard Bruderer, 'A Landscape Theory of Alliances with Application to Standards Setting' (University of Michigan, Graduate School of Business Administration, Working Paper No. 666, 1991).

In economics, the main approach to alliance formation is to calculate and compare 'coalition structure values' for each possible configuration[44] and then use a standard game theoretic analysis to determine both the alliance configuration that is likely to emerge and the stability of each configuration. Unfortunately, the coalition structure value framework is difficult to apply to empirical data since it requires identifying and quantifying payoffs for each actor in every conceivable configuration. Unlike the reliance of landscape theory on pairwise propensities, payoffs for each firm depend in complex ways on choices made by all the other firms. For example, in the standards setting case, the size of the market will vary with the number of standards, and a given firm's market share will vary with (among other factors) how quickly the firm can bring a product to market relative to the other firms. Not surprisingly, there has not been a single empirical test of the coalition structure values approach for the problem of standards setting. There is, however, a rich descriptive and theoretical literature on the subject.[45]

The specific case of standards setting chosen for a test of landscape theory is the struggle by technical workstation manufacturers to create a Unix operating system standard. Technical workstations are powerful desktop computers, typically used in engineering and scientific applications. World-wide sales were $2.5 billion in 1987 and are projected to reach $10 billion in 1991. The technical workstation market has depended on several incompatible implementations of the Unix operating system. The attempt by two firms to impose a Unix standard failed utterly. Out of this failure, two opposing alliances formed in 1988.

The application uses the market-related size and two attributes of each relevant firm to predict their commitment to the standards promoted by the two alliances. The relevant firms included the eight firms that had at least 1 per cent of the world-wide technical workstation market in 1987. Together these firms accounted for over 95 per cent of the relevant market. Also included is AT&T because it held the copyright for the parent version of Unix, licensed

[44] Guillermo Owen, 'Values of Games with a Priori Unions', in R. Hein and O. Moeschlin, eds, *Essays in Mathematical Economics and Game Theory* (New York: Springer-Verlag, 1977), pp. 77–88.

[45] See Michael Katz and Carl Shapiro, 'Network Externalities, Competition, and Compatibility', *American Economic Review*, 75 (1985), 400–24; Michael Shapiro and Carl Shapiro, 'Technology Adoption in the Presence of Network Externalities', *Journal of Political Economy*, 94 (1986), 822–41; Joseph Farrell and Garth Saloner, 'Co-ordination Through Committees and Markets', *Rand Journal of Economics*, 19 (1988), 235–52; Stanley M. Besen and Garth Saloner, 'The Economics of Telecommunications Standards', in R. W. Crandall and K. Flamm, eds, *Changing the Rules: Technological Change, International Competition, and Regulation in Communication* (Washington, DC: The Brookings Institution, 1989); Gary Hamel, Yves L. Doz and C. K. Prahalad, 'Collaborate With Your Competitors – and Win', *Harvard Business Review*, 67 (1989), 133–9; Thomas M. Jorde and David J. Teece, 'Innovation and Co-operation: Implications for Competition and Antitrust', *Journal of Economic Perspectives*, 4 (1990), 75–96. For a review of the role of compatibility standards see Paul David and Shane Greenstein, 'Selected Bibliography on the Economics of Compatibility Standards and Standardization', *Economics of Innovation and New Technology*, 1 (1991), 3–41.

Unix to manufacturers, continued to develop Unix in 1987 and was a potential entrant to the technical workstation industry. The size of the eight manufacturers was measured by their 1987 market share. The size of AT&T was based on the median estimate of four computer industry experts of the importance of AT&T with respect to its influence in establishing a Unix standard.

Before collecting the sample of firms for this study, two competitive attributes were identified that were expected to influence the propensities to collaborate in the Unix standards setting case. First, some computer manufacturers have a significant design capability, while others are primarily assemblers of other firms' designs. Secondly, some computer companies specialize in the workstation market, while others are generalists with many lines of computer-related products. In each category, firms with similar capabilities were expected to have difficulty working together because of the head-to-head competition in the markets they address. Firms with different capabilities were expected to complement each other. Of the nine firms in this study, five were workstation specialists and all nine possessed design capability. To determine the propensity of a pair of firms, a value of 1 was assigned when two firms had complementary attributes (specialist–generalist), and -1 when attributes conflicted (two specialists, two generalists or two designers). These values were then summed to measure the propensity for each pair of firms. Since every firm is a designer, this results in total propensity of 0 for distant rivals (generalist–specialist pairs) and -1 for close rivals (generalist–generalist pairs or specialist–specialist pairs).[46]

The predictions generated by landscape analysis of the Unix case are shown in Table 1, along with the attributes and the size of each firm. With nine firms, there are $2^9/2 = 256$ unique alliance configurations.[47] The resulting landscape has two configurations of locally minimal energy, and these are the predictions of the theory. They have equal energy and equal basin sizes. These are shown in Table 2 as Configuration 1 and Configuration 2.

Historically, the first move in the alliance process was AT&T joining with Sun. Knowing this allows unique prediction, namely Configuration 1. In Configuration 1, six of the seven commitments made after the initial AT&T–Sun link-up are predicted correctly. The probability of a result this good happening by chance is one chance in sixteen.[48] Even more importantly, this configuration correctly accounted for the alignments of all the major firms in the workstation market and most of the smaller ones as well. In all, it correctly accounted for 97 per cent of the total size of the firms in the sample.

46 Here is another derivation of the same propensity values. Firms prefer to be aligned with each other to increase the size of their alliance, but they prefer not to align with rivals. For distant rivals, these two considerations counterbalance, making $p_{ij} = 0$. For close rivals, the rivalry consideration dominates, making $p_{ij} = -1$.

47 As in the international cases, it was assumed that there would be at most two groupings.

48 There are $2^7 = 128$ ways of assigning the remaining seven firms to two alliances. Of these, one is completely correct and seven are off by one firm. Therefore, the probability of getting six or more of seven right by chance is $(7 + 1)/128 = 1/16$.

TABLE 2 *The Two Configurations Predicted for Unix Alliances**

	Configuration 1 Alignment 1	Alignment 2
Alliance 1	Sun (28.9, S) Prime (1.0, S)	DEC (20.0, G) HP (11.5, G)
Configuration 2		
Alliance 2	AT&T (28.5, G) IBM (3.8, G)	Apollo (21.2, S) Intergraph (4.4, S) SGI (4.4, S)
Nearest empirical match†	Unix International	Open Software Foundation

*Size is shown in parentheses, along with whether the firm was a computer generalist (G) or technical workstation specialist (S). All firms had a design orientation.
†In Configuration 1, only the IBM prediction is wrong.

In sum, landscape theory did a good job of predicting business alliances as well as international alignments. With this encouragement we turn to other potential applications of the landscape theory of aggregation.

OTHER POTENTIAL APPLICATIONS

Coalitions of Political Parties in Parliaments

Most democracies have a parliamentary system in which political parties must form a majority coalition in order to govern. At least fourteen theories have been proposed to account for which coalitions will actually form, and empirical research on a score of countries shows that the ideological distances between the parties helps explain the results.[49] Data are available for hundreds of coalitions in all. While most studies use only ordinal measures of ideological distance, interval level measurement is also available.[50] If the ideological distance between any two parties is regarded as inversely related to their propensity to work together, then landscape theory offers a natural way to predict parliamentary coalitions.

Social Networks

Sociologists describe social networks based upon the pairwise relationships between individuals. A classic example is the Western Electric Bank Wiring

[49] Abraham DeSwaan, *Coalition Theories and Cabinet Formation* (San Francisco: Jossey-Bass, 1973).

[50] Michael-John Morgan, 'The Modeling of Governmental Coalition Formation' (doctoral thesis, Political Science Department, University of Michigan); Michael Laver and Norman Schofield, *Multiparty Government: The Politics of Europe* (Oxford: Oxford University Press, 1990); Michael Laver and W. Ben Hunt, *Policy and Party Competition* (New York: Routledge, forthcoming).

Room, with fourteen men each having six types of social ties.[51] Other examples are detailed data about the selection of a dorm head at MIT[52] and dynamic data about friendship networks.[53] Given the data about the pairwise propensities of individuals to be friends, landscape theory offers a natural way to predict how a number of people will form clusters of friendships.

Social Cleavages in Democracies

Social cleavages based upon ethnicity, race, religion, class and so forth exist in every society, although which cleavages are most important differs from one society to another. In a democracy, political parties typically try to build electoral coalitions in part by paying close attention to the issues that appeal to those on one side or the other of these cleavages. Consequently, the structure of electoral coalitions and the stability of a political system depend in part on whether the major cleavages in a society are mutually reinforcing or are cross-cutting.[54] Cleavage theory has a wide application, from debates over redistricting in the United States to the prospects for survival of a multinational state such as the Soviet Union.

Landscape theory offers a way of formalizing cleavage theory and relating it to other coalition theories. To apply landscape theory to social cleavages, the propensities of groups to ally could be based on their pairwise conflict of interest. For example, from the 1930s to at least the 1960s, blacks and Catholics in the United States shared many political interests and therefore a political party could efficiently appeal to both. To account for an alignment such as the New Deal Coalition, landscape theory would need to be extended to allow each group to belong to a coalition to some degree rather than completely or not at all. With this extension, landscape theory could predict how changes in pairwise propensities among the groups would affect the resulting electoral coalitions. For example, it could address the question of whether in a given two-party system there is a single 'natural' electoral coalition configuration at each point in time. It could also characterize conditions under which electoral coalitions would change rapidly from one local minimum to another resulting in so-called 'critical elections'.[55]

Landscape theory could also compare the cleavage structures of different societies to analyse the degree to which each country's cleavage pattern results

[51] George C. Homans, *The Human Group* (New York: Harcourt Brace, 1950); Peter Carrington and Greg H. Heil, 'Coblock: A Hierarchical Method for Blocking Network Data', *Journal of Mathematical Sociology*, 8 (1981), 103–31.

[52] Kathleen Carley, 'An Approach for Relating Social Structure to Cognitive Structure', *Journal of Mathematical Sociology*, 12 (1986), 137–89.

[53] Theodore M. Newcomb, *The Acquaintance Process* (New York: Holt, Rinehart and Winston, 1961).

[54] Edward Alsworth Ross, *The Principles of Sociology* (New York: Century, 1920); Robert A. Dahl, *Pluralist Democracy in the United States* (Chicago:Rand McNally, 1967).

[55] Walter Dean Burnham, *Critical Elections* (New York: Norton, 1970).

in a 'frustrated system'.[56] An interesting feature of cleavage theory is that it proposes that democratic systems are actually more stable if their cleavages result in a frustrated system. The reason is that when cleavages are cross-cutting, few people will be completely dissatisfied.

Organizational Structures

An important principle in organization theory is that an efficient organization is structured so that jobs that require frequent interaction are placed near each other in the organizational structure.[57] In landscape theory, the propensity of two jobs to be near each other can be measured by their natural rate of interaction. The distance between two jobs in a given organizational structure can be regarded as the number of layers of the organization that have to be ascended to reach a common boss. Landscape theory might help account for how organizations can have two completely different stable configurations, as when the State Department can be set up along functional lines or along geographic lines.

CONCLUSION

Landscape theory is able to predict international alignments and business alliances. It also offers promise in applications to parliamentary coalitions, friendship networks, social cleavages and organizational structures.

To improve the foundations of landscape theory, two activities would be helpful. First, the particular functional form that the theory takes should be justified in rigorous terms. One way to do this would be to develop a formal set of axioms about the way actors of bounded rationality behave in settings that allow aggregation. The axioms could specify how information about size and propensity are used by the actors in making their myopic choices and how the choices are made incrementally. Additional axioms would specify the allowable forms of aggregation and the symmetry of propensities. With these axioms it should be possible to demonstrate that the formula for energy of a configuration is the appropriate one, that the dynamics of the system must correspond to decreases in energy and that the only stable points of the system are the configurations that have locally minimum energy. Moreover, such a set of axioms would be useful in showing how landscape theory relates to other theories of choice and how variations in landscape theory could lead to other dynamics.

The other way in which the foundations of landscape theory could be improved is by providing guidance on how the concepts of the theory should be operationalized in a particular application. Having a well-developed set of ideas about how propensity should be measured would be particularly helpful.

[56] For example Seymour M. Lipset and Stein Rokkan, *Party Systems and Voter Alignments: Cross-National Perspectives* (New York: The Free Press, 1967).

[57] James D. Thompson, *Organizations in Action* (New York: McGraw-Hill, 1967).

Obviously, the details of measurement of propensity will vary from one application to another. Nevertheless, the use of a limited number of factors to determine all the pairwise propensities is likely to be widely applicable. So it would be helpful to develop some guidance on how these factors should be chosen, and how they should be coded and combined. An example of such guidance is the following: if there are complementary characteristics of actors that allow positive externalities from joint action, then such complementary characteristics should be included as one of the factors, and that factor should be coded so that actors who are dissimilar in this way have a positive propensity to work together.

To appreciate the overall orientation of landscape theory, an analogy to research on the Prisoner's Dilemma will help. The value of the Prisoner's Dilemma is not only that it gives accurate predictions, but also that it leads to a deeper understanding of political processes such as the way in which the shadow of the future is essential for co-operation among egoists. Likewise, the intended value of landscape theory is not only in providing accurate predictions, but also in leading to a deeper understanding of aggregation processes such as the way in which an energy landscape can determine which configurations are stable. Just as the Prisoner's Dilemma helps us to see important similarities across a wide range of applications, landscape theory helps us see how the aggregation processes in many different areas do indeed have a surprising similarity when viewed with the aid of a common theoretical framework.