INTRODUCTION TO THE GRAPH THEORY AND STRUCTURAL BALANCE APPROACHES TO INTERNATIONAL RELATIONS

LEVEL

by

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PREFACE

This paper is a summary introduction to some of the graph theoretical work being done in connection with the World Event/Interaction Survey. The paper discusses some of the rationale for adopting a graph theoretical approach to international relations. Also included are some of the matrix algebra algorithms that have been developed for operationalizing the notion of structural balance and an illustration of how the technique might be used to analyze the structure of international relations.

The reader should bear in mind that this paper is introductory, and that many of the ideas presented here have been refined and presented in greater detail elsewhere.

INTRODUCTION

If the relations among nations are understood to be interrelated and extremely complex, it should be expected that the techniques for monitoring and analyzing those relations may also have to be interrelated and complex. Even when one succeeds in converting a flood of incoming information about international relations into data which can be computerized for summary and analytic purposes, one still faces the need to interpret a wealth of information against the broad pattern of international affairs. In performing this task, an analyst cannot rely solely on his intuition to render a complex set of indicator data comprehensible to provide him with the systematic overview that his data can undergird. In other words, having created a set of working indicators that describe some main features in the international event stream, the analyst has not yet constructed a facsimile of the international system to describe the status of relations among nations and, on the basis of present and past performances, to project possible system futures. The task in this paper is to show that graph theoretical models can be applied usefully to this end. Specifically, this will involve a discussion of some of the ideas that underly graph theoretical approaches to social phenomena, and an illustration of what appears to be a powerful theoretical notion that relies heavily on graph theory for its operationalization.

THE GRAPH THEORY APPROACH

Graph theory is a powerful tool that facilitates the handling and interpretation of many variables and complex data sets without the loss of information that can result from using summary statistics or multivariate analysis. Graph theory has been refined and defined in mathematical terms to render it amenable to computer operations.[1] We shall proceed next to describe how graph theory may be used to organize and interpret indicator data produced by the WEIS processor.[2]

Practical foreign policy analysis focuses on what is going on in the world. Not only is knowledge needed about who is doing what to whom in the international system, but it is needed to establish how the action affects other members of the system. These are macro-concerns. They are concerns for the entire web of international relations and how the relations that compose that web are interdependent.

As a package of indicators, the WEIS processor provides information about the entire web of international relations, but the output needs to be arranged and used in a fashion that renders the whole comprehensible. As an example, consider the output of INTSCAN1.[3] It computes standard scores on a routine basis for each dyad in the international system. Within that array of z scores exists data of a complex set of relationships and not merely the information of individual readings. With 25,440 possible dyads in the international system of 160 actors to be taken into account, it is literally impossible for human beings to monitor each dyad without some mechanical aid. This is before it is even realized that dyads are interdependent and that there are therefore multiple associations to be analyzed and interpreted. The difficulties associated with managing the data of multiple relations are formidable.

An example of international relationships is useful in illustrating some of the basic notions in graph theory. It can be easily argued that U.S. and Russian relations are dependent on the relations of Israel and Egypt. Likewise, it can be argued that U.S.-Egyptian relations are dependent on Egyptian-Israeli or Israeli-U.S. relations. In this situation one might note that when shifts in the pattern of Egyptian-Israeli interaction occurs, one can expect effects to be felt in the relations among other nations involved in the Middle East. A major shift in relations or in international event flows will produce effects that flow out through a matrix of interconnected relations much the way a rock dropped in a pond creates waves that play out through the entire pond. The analyst needs to know which actors are involved in the matrix and what the nature of their involvement is. He would also like to know how actors may be expected to react to shifts in Egyptian-Israeli relations and, should a shift occur, he needs to know how, in fact, they are reacting to that shift.

Operationalizing a graph theoretical model first calls for conceptualizing international relations in terms of a square matrix (called in graph theory terms, an "adjacency" matrix) where each row and its corresponding column signify a single country in the international system.

Using the WEIS alpha codes, a rudimentary Middle East conflict matrix is shown:[4]

OUTPUT \ INPUT	USA	USR	UAR	ISR	JOR	SYR
USA						
USR						
UAR						
ISR						
JOR						
SYR						

FIGURE 1: MIDDLE EAST CONFLICT MATRIX

The cells in the matrix signify the possibility of a relationship of each nation with each other nation. Whether or not such a relationship exists is, of course, dependent on the content of the event data. Also, hypothetical data provided for modeling purposes might be employed. In the above matrix, the entire row labeled "UAR" would comprise the total event output of Egypt with each cell entry being Egypt's output to the nation at the head of the appropriate column. In columns where zero entries appeared, Egypt would not be considered to be directing a relation. Using a graph theory convention, we assume that Egypt should not be thought of as having an international relation with itself. Thus, where the UAR row intersects the UAR column a zero would represent no relation. The sum of the UAR row entries would represent the total of Egypt's output to every nation being considered, just as the sum of the UAR column entries would represent the total of Egypt's intake from every nation being considered.

A matrix filled with international interaction data for a particular time period contains information about the structure of international relations for that time period in the same manner that a snapshot contains information about the events occurring at the time the snapshot was taken. To carry the analogy further, a sequence of matrices would contain information about how international interaction patterns are unfolding just as a series of snapshots reveals how an action series unfolds.

To use one or a series of structural matrices to gain access to the information about interrelated dyads, an investigator must perform certain matrix algebra operations. For purposes of illustration, imagine a Middle East interaction matrix whose cells contain information about the quantity of interaction among Middle East countries for a certain period of time. Simply by setting a significance threshold and intersecting the matrix with its transpose, the analyst finds all of the dyads whose interaction was above the threshold for a particular time period. A series of these operations performed before, during, and after a known crisis period, such as the June War, would reveal the shifts in dyadic interaction patterns that occurred during the crisis period.[5] An analyst monitoring the steady unfolding of international relations and comparing present patterns with those of the past on the basis of quantitative shifts alone would gain a broad view of the direction in which dyadic interaction patterns were moving. He could tell if certain pre-crisis shifts were repeating themselves, and thereby be forewarned of a pending crisis.[6] Of course such a technique could be automated and is, in fact incorporated in the WEIS processor to draw attention to interaction shifts according to an analyst-specified algorithm. There is no need to have anyone pore over daily listings of structural matrices.

Given a limited shift in relations among nations, the natural question arises concerning concomitant shifts among nations not involved in the original shift. The standard monitoring procedure has a z-scored volume indicator that measures variations in nations behavioral intake and output. It is safe to assume that some international relations are responsive to shifts in other international relations, and the question becomes which relations are interrelated and to what degree. Combining z-scores with a series of structural matrices, an analyst can monitor shifts in relations and follow them as they play out through the system. Projecting the degree to which present interaction variations are felt throughout the entire system can be done by invoking an algorithm that raises a structural matrix to certain exponential powers that are derived from past performance and dependent upon the degree of the original interaction shift.

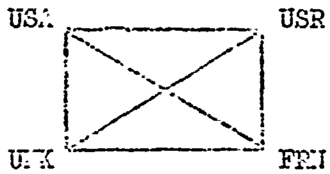
The two techniques that have been described are but a sample of the simpler techniques that graph theory provides for easily managing information about an entire network of international relations. Other, more sophisticated theoretical notions and monitoring techniques may be developed as the following discussion will illustrate.

The monitoring that is most easily conceptualized is the gauging of actions emitted or received by a single nation. Indeed, the single country perspective is one basis of the WEIS processor. However, the reader probably will agree that another perspective exists, namely, that where the principal unit of analysis is not single nations, but pairs of nations. Frequently, analysts move to this level intuitively when they state such things as "Indian-Pakistani relations are deteriorating" or "East German and West German relations are improving." Combined relations can be broken down into their single-nation components, but it is also true that by watching dyads a great deal about international relations can be learned. Studies of the well-known arms race/conflict spirals are a case in point.

Arms race/conflict spirals, or Richardson processes as they are called after the man who first described them, are dependent on the mutual responsiveness of at least two nations. The analysis problem is connecting seemingly disparate intake-output information about a large number of single nations in mutually responding pairs and then monitoring their linked interaction as single units of analysis. Graph theory handles this problem easily. It contains techniques based mainly on simple intersection matrices for converting the standard WEIS indicators to a dyadic perspective. Monitoring dyads in this fashion should detect early shifts in dyadic behavior which may lead to more dramatic shifts in the future. No doubt this type of monitoring goes on regularly in some fashion where key dyads are involved, as in Russian-United States relations or Russian-Chinese relations, but with graph theory techniques it can go on regularly and economically with every dyad in the international system being monitored to provide advance notice of when, say, Moroccan-Algerian or Chilean-Argentinian relations begin deviating from their established patterns. Such advance notice might come before a dramatic shift occurred and would lead to at least one action: a closer analysis of the situation to determine what direction it might take.

Moving from a dyadic perspective to a triadic perspective greatly increases the complexity of monitoring relations among nations, but, as in moving from single countries to dyads, graph theory can accommodate the shift. Before discussing some of the advantages of triadic analyses and some of the questions that such a perspective can answer, we shall explain why the triadic perspective is the maximum level of complexity to which monitoring which uses graph theory to analyze the relations among single nations should aspire.

The reason for choosing triads as the maximum unit of analysis within a graph theoretical context lies in the nature of modern international interaction. While all nations do not have contiguous boundaries, due to twentieth century conditions, all nations can interact in one-step flows. Transport and communication technologies put virtually all nations in direct contact. For the analysis of international relations this means that, save for a few cases, it is necessary only to observe what nations do directly to one another in order to determine the state of their relationship. Granted, one nation sometimes does something to another nation through a third party. Two good examples are the United States using Swiss offices in Havana and Spanish offices in Cairo. But it is difficult to imagine the United States reaching Egypt by first going through the Swiss and then the Spanish governments in a single line. Even when such cases occurred in the international system, they would be interesting only for their uniqueness. Further, any multi-step relational chain falling under the principle of transitivity ultimately could be reduced to a one-step chain where its beginning and ending were the only points emphasized. With one-step interaction linkages between nations, any nation can reach each nation in any dyad in only one move, so that a model of interacting nations containing more than three nations could always be reduced to its triadic components as the following "model" of four nations illustrates.



In this illustration there are four triads; each nation is in three of them, the number of nations involved is four, and the entire network can be constructed from knowledge of the triads it contains. Adding a fifth nation would create the addition of one dyad if that fifth nation maintained relations with only one member of the existing group. If the fifth nation maintained relations with two members of the existing group, presumably those relations would be affected by the relations being maintained by the original members of the group so that the two additional dyads would have to be considered in the context of a triad.

A word of caution should be included at this point about moving to a triadic level of analysis. It has been successfully demonstrated that the single relations that compose a dyadic relation are highly interdependent. Such is not always the case with triads where research is beginning to show that some triads are not composed of completely interrelated relations. Several mediating variables seem to be involved and they determine whether or not it is meaningful to consider a particular triad as a result of analysis. The first influence might be called "spheres of action" and is related to the extent each of three nations are involved with each other as measured by the amount of interaction occurring among them in a particular sphere of action. A sphere of action might be the Middle East where the United States, Egypt, and Israel are all highly involved with each other. In such a sphere of action it would not seem to matter if all sides of an interaction triangle reflected a high degree of involvement for so long as two sides reflect this involvement, the conclusion seems to be that the third side will be affected by fluctuations in the activity of the other two sides.

By invoking this principle in a policy-relevant situation such as that where the United States was highly involved in the affairs of Pakistan and India through arms and aid shipments and where Pakistan and Indian relations flared into a brief war, one might be led to conclude that if the United States had been forewarned of the incipient military encounter through the monitoring of the Pakistan-India dyad action flow, the United States could have avoided getting caught in the cross-fire by temporarily reducing its involvement in the triad. This is speculative, of course, but the possibility suggests how the concept might be employed in anticipatory planning.

Another variable affecting the extent to which triadic relations are interdependent is the substantive issue over which interaction is occurring. In cases where members of triads are all highly involved with each other, discriminating among issues would appear not to matter. However, when the level of involvement among all three nations of a triad is not particularly high as measured by the quantity of interaction, or when their involvement spans more than one sphere of action, thinking in terms of triadic interaction over specific issues appears to be useful. A case in point might be the triadic relations among the United States, South Africa, and the Congo where, so long as the interaction issue is not apartheid, it would seem that the relations among the three countries would not be interrelated.

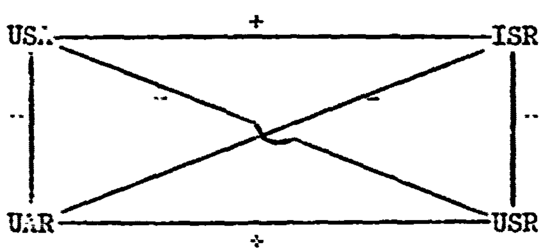
In choosing a triad as a unit of analysis, then, the analyst must decide on the basis of some criterion that it makes sense to view this or that triad either alone or in a network of interrelated triads. Two mediating variables for doing this have been suggested; they are important to keep in mind. As the WEIS processor has evolved to its present form, only the variable dealing with amount of interaction can be operationalized and this is primarily for demonstration purposes. Even so, with the present capabilities of the WEIS processor, one can learn a great deal about interaction in a triad when the quantity of interaction is transformed to indicator data, and then to data that in some way reveals the <u>quality</u> of interaction that exists among nations.

Thus far in this paper the argument has been (1) that international relations are complex and interrelated, and (2) that graph theory is a vehicle for monitoring efficiently the entire network of international relations. Graph theory provides the conceptual ordering and the algorithms needed to bring the computer into the analysis. If it has not become apparent already, the point should be made now that graph theory is a general tool that is user-dependent for the direction of its operationalization. That is to say, graph theory does not automatically monitor the z-scores of pairs of nations, but graph theory is a tool for finding linked pairs of z-scores and then combining them into a single indicator of dyadic relations, if that is the analyst's desire. The case is the same with other monitoring outputs: HRELs, time series analysis, and exponential smoothing functions; the analyst must decide that he wishes to apply these indicators and predictors to linked dyads and/or triads. When a decision has been made to proceed in this or that fashion within a graph theoretical context, the steps of operationalization are fairly easy.

As work with graph theory and its special applications to international relations has proceeded, one thing has become apparent: graph theory can be used to operationalize intuitively compelling notions that get at the heart of what many international relations analysts have been attempting to do. One example is the notion of structural balance. It hinges on the idea that nations maintain what may be thought of as positive and negative relations among themselves.[7] Its operationalization results directly from using graph theory to monitor international relations.

Analysts and decision-makers are continually acting on the basis of whether or not relations between nations are positive in the sense that they are "good," "friendly," or "cooperative," or negative in the sense that they are "bad," "hostile," or "uncooperative." Charting the structure of international relations conceived in a positive-negative dimension has proven elusive, and has always been a problem for foreign policy analysis. No doubt, during the "Cold War era" the matter of sorting out positive-negative relations was less problematical than it is now, since American-Soviet polarization tended to pull most states into one camp or the other. With the increase in the number of new nations and with the rise of a "Third World," a breakdown in bloc solidarity and a diffusion of power and conflict throughout the international system, a model of international relations that is based solely on the positive and negative relations of East and West is no longer appropriate. Observers and analysts of foreign policies now must be aware of and react to subtle changes in the quality of relations which, while they may be somewhat related to an East-West system, more often are becoming unrelated to such a system. The United States--by no means unique--must continually deal as an unwilling third party with shifting relations over which it has no direct control yet with which it is involved. The list of such relations is long and includes India-Pakistan relations, Russian-Chinese relations, Greek-Turkish relations, Israeli-Arab relations, Egyptian-Saudi relations, Iran-Iraqi relations, and so on.

Regarding alliance structures or positive and negative relations, it might be said that nations are structure-bound in terms of whom they interact with and how. An example from the history of international relations illustrates the point. Given hostile relations between Egypt and Israel, it is difficult to imagine how, so long as the United States continues to supply arms to Israel, there can be positive relations between Egypt and the United States. Should the U.S. decide to establish better relations with the Egyptians, good relations with Israel might have to be sacrificed, at least, for as long as Egypt and Israel remain hostile toward each other. Here the perspective is triadic rather than dyadic. Add the Soviet Union to the system, and it can be argued that four triads have been created as the following diagram illustrates:



Plug more countries into the system and the number of additional triads that are created grows geometrically until it becomes impossible to

```
login(uscu010,rkia04af)
PASSWORD: [redacted]
GOOD AFTERNOON; USER03; TIME  15:58:14  8/04/71;

load(NOVAL,KIB01)
xeq

YOU MAY BEGIN BY TYPING IN THE DIMENSION OF YOUR MATRIX
DIM
5
TYPE IN THE A(S) MATRIX
AS(1,1)
0 1 0 1 0
AS(2,1)
1 0 1 1 1
AS(3,1)
1 1 0 1 1
AS(4,1)
1 1 0 0 1
AS(5,1)
1 1 1 1 0
NOW, TYPE IN COUNTRIES INVOLVED ALLOWING 3 SPACES FOR EACH
USAISRJORUARPLO
ROLL TO NEW PAGE AND HIT RETURN

                    *****
          (this is a sample of the output)

                  UNSIGNED CYCLES

     ISR      ====>      USA      ====>      UAR
     ISR      ====>      JOR      ====>      USA
     PLO      ====>      USA      ====>      UAR


                 UNSIGNED SEMI-CYCLES

  SENDER SENDER | SENDER RECEIVER | RECEIVER RECEIVER
  ---------------------------------------------------
       USA      |       UAR       |        ISR
       ISR      |       JOR       |        USA
       ISR      |       UAR       |        USA
       ISR      |       PLO       |        USA

logout
TIME 16:05:23; TIME USED: CPU 00:00:30; TERM 00:07:09;
```

FIGURE 2: EXECUTION OF NOVAL ON AN IBM TERMINAL

keep them in mind or even to recognize them without the aid of a computer and appropriate algorithms.

The point requires emphasis that systematically operationalizing a triadic approach to the analysis of international relations aids immensely the study of country relationships when a device such as the WEIS processor is in operation. Before acting or reacting to developments in the international system one needs always to ask what reactions are third parties likely to have to this or that plan or policy. When monitoring relations between any two nations one needs to know how third parties are likely to become involved. Usually the answer hinges first on the extent to which the third party is involved in the triad and, second, on the valence of the third party's relation with each of the other members of the triad. Therefore, what an analyst needs is a procedure that (1) will assign valences to relevant relations, and (2) will analyze a structural matrix with valenced entries for the underlying triadic structures it contains. Also needed are procedures to determine the ways in which triads are linked so that the stresses and strains that develop among interrelated triads may be gauged. The analyst requires an anticipatory strategy to know which relations are likely to change or which new ones are likely to be created. To meet these requirements is no easy task, but the job needs to be done if international relations analyses are to break out of their typically dyadic perspective and move to a higher level of analytical sophistication.

A reliable interaction valencer that detects subtle shifts in relations along their friendly and unfriendly dimensions has been incorporated in the WEIS processor as a sub-routine, SCALOR. Thus, it is a simple matter for the analyst to assign valences to the international relations that are of interest to him.[8]

Analyzing a structural matrix for the underlying triadic structures that it contains is also an easy matter. We have developed four programs that perform this function: KOVAL, DATA, CYCLES, and SEMICYCLES.[9] At present they are stored in the Conversational Programming System Library at the University Computing Center, which means that they may be invoked by an analyst's command from his office if he is equipped with a telephone and an IBM 2741 typewriter terminal or its equivalent.

Each of the four programs performs special functions that are consistent with the principles presently being discussed and the algorithms to be presented later in this paper. For instance, NOVAL analyzes a structural matrix and finds all of the triadic structures it contains without regard for valenced relations. This ability of NOVAL to disregard valences is useful if the analyst wishes to monitor mutual responsiveness in triadic structures when z-scores, HEELs, or quantitative shifts in intake/output flows are being considered. DATA is an intermediary program that renders structural matrices containing information about valenced relations operational for interpretation by CYCLES and SEMICYCLES. Thus, DATA performs an analytic function and stores information in machine-readable data files, while CYCLES and SEMICYCLES access those files and present their content to the analyst.

The four programs embody a complex set of algorithms which provide the analyst with numerous capabilities from data storage, to description, to hypothesis testing, to monitoring and prediction. The internal complexity of the programs is of no real interest to the analyst because when he uses them he "interacts" with the computer through an IBM terminal. For illustration purposes, we have shown how NOVAL is executed on an IBM terminal. This should serve two functions: (1) it should demonstrate the ease with which the programs may be used, and (2) it should demonstrate the additional computer terminal function that may be used in automated foreign affairs analysis.

THE NOTION OF STRUCTURAL BALANCE

What follows is a fairly detailed explanation of the structural balance notion and the algorithms that led to the development of the four programs. After that a demonstration on data from the WEIS collection is provided of how graph theory and the notion of structural balance can be used to analyze a situation and gain insight as to its pending future.[10]

The basic concept of structural balance maintains that for the relations among three actors to be balanced, they must all be positive or two of them must be negative and the third positive. This principle is reflected in the Middle East proverb that says: "The friend of my friend is my friend; the friend of my enemy is my enemy; the enemy of my enemy is my friend; and the enemy of my friend is my enemy." This statement can be demonstrated graphically. The two triads shown in Figure 3 are balanced, the first with all positive relations and the second with two negative relations and one positive relation:

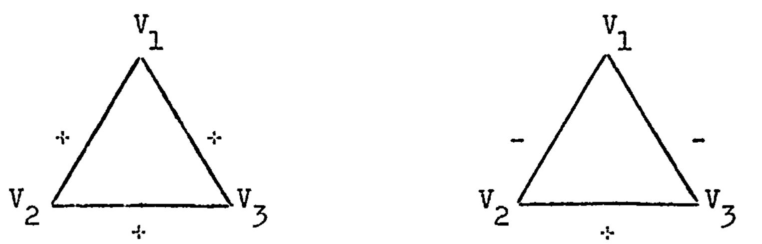


FIGURE 3: BALANCED TRIADIC CONFIGURATIONS

According to the notion of structural balance any other triadic configuration of positive and negative relations is unbalanced. There are two unbalanced triadic configurations: the first with two positive relations and one negative relation, and the second with three negative relations. They, too, can be depicted graphically:

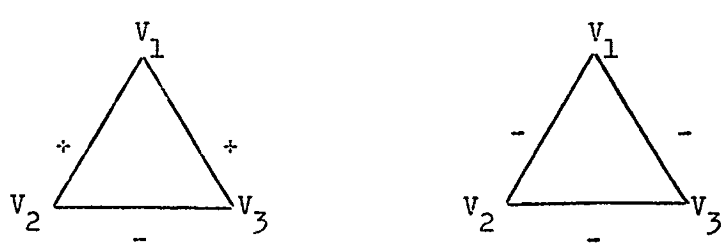
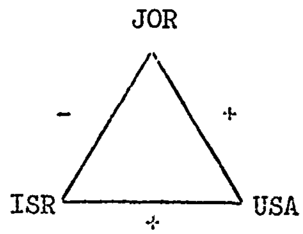
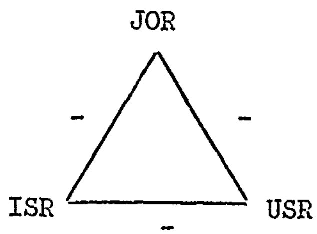


FIGURE 4: UNBALANCED TRIADIC CONFIGURATIONS

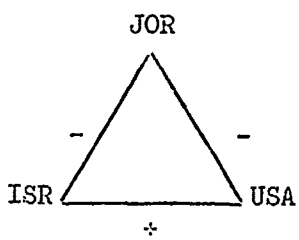
Given a set of unbalanced relations, the presumed tendency is for those relations to become balanced. That is, in unbalanced triads, a strain towards balance is expected to exist. Several international relations situations where triadic relations are unbalanced easily come to mind. For example, it appears that the relations among Jordan, Israel, and the United States are unbalanced as the following graph illustrates.



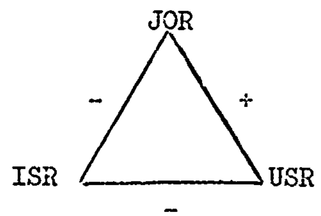
Similarly, the relations among Jordan, Russia and Israel are considered to be unbalanced.



In each of these triads, a strain towards balance should be anticipated. In the first triad, a shift to the negative in Jordan-U.S. relations could occur with the triad becoming balanced and with Jordan invoking the principle, ". . .the friend of my enemy is my enemy." Then the new balanced triad would appear as:



In the second triad a shift to the positive could occur with Jordan invoking the principle, ". . .the enemy of my enemy is my friend." The new balanced triad would appear as:



If we now generalize the possibilities for a set of three nations, the fact is established that their relations can assume eight balanced and unbalanced configurations as shown in Figure 5. In studying these possible configurations, one should note the similarity between types "a", "e", "f", and "g" and the two balanced triads described on page 13. Type "a" is balanced with all positive relations and types "e", "f" and "g" are

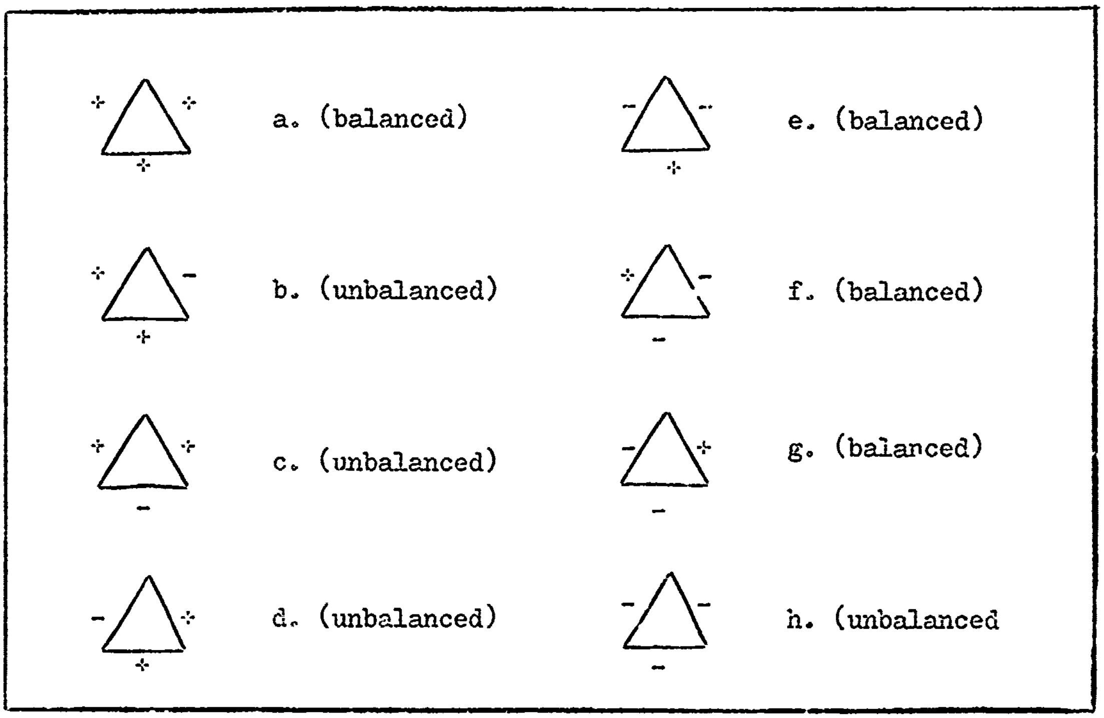


FIGURE 5: BALANCED AND UNBALANCED TRIADIC CONFIGURATIONS

balanced with two negative relations and one positive relation. In parallel, one should note the similarity between types "b", "c", "d", and "h" and the two unbalanced triads described on page 13. Type "h" is unbalanced with all negative relations, and types "b", "c", and "d" are unbalanced with two positive relations and one negative relation.

The reason for categorizing one type of configuration for triads with either all negative relations or all positive relations and three types of configurations for triads with mixed positive and negative relations is understood easily when it is realized that rotating a triad with relations of the same valence by 120° within the boundaries of a three-sided group will not change the valence of the relations among the members of the group. To explain this further, if three actors are connected by all positive relations, regardless of how the structure of their relations is rotated, they will always be connected by positive relations. On the other hand, rotating an interaction structure containing positive and negative relations will change the valence of the actors' relations with each rotation. The principle is illustrated in Figure 6.

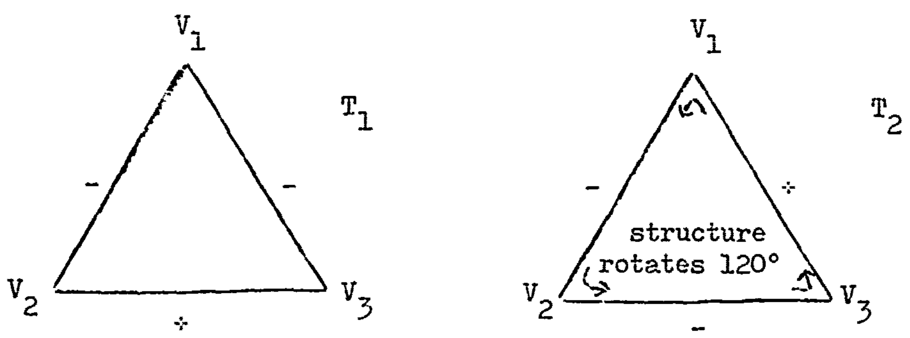


FIGURE 6: MIXED-VALENCE INTERACTION STRUCTURE BEFORE AND AFTER ROTATION

In the example above, the interaction structure remains unchanged from T_1 to T_2 and is balanced with two negative relations and one positive relation. However, the relations among the actors have changed from T_1 to T_2; the V_2V_3 relation changed from positive to negative, and the V_1V_3 relation changed from negative to positive. In triads with both positive and negative relations it makes a big difference how the actors are positioned around the interaction structure, while in triads with homogeneous relations it does not. Thus, the expansion of a four-category system to an eight-category system for describing valenced relations among a generalized set of points is justified.

In graph theory there may be a concern for the <u>direction</u> of relations, so that T_1 above may be redrawn to indicate that the various actors were directing negativeness or positiveness to their partners in the triad.

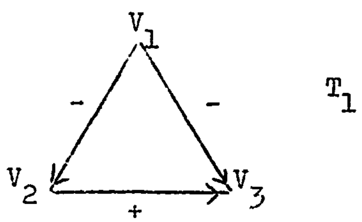


FIGURE 7: "SEMICYCLE" TRIADIC DIRECTIONAL RELATIONSHIP

As T_1 has been redrawn, V_1 directs relations to V_2 and V_3; and V_2 directs a relation to V_3. In the jargon of graph theory, this configuration describes a "semicycle" since three lines connect all three members of the triad. A characteristic of semicycles is that by starting at any apex in the triad and following the direction of the lines one may not return to his original starting point without passing over one of the lines twice. That is, one may not get all the way around the triad by following the direction of the relations.

Compare the redrawn T_1 with T_2 as it is shown below in Figure 8:

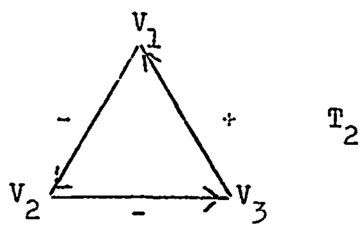


FIGURE 8: "CYCLE" TRIADIC DIRECTIONAL RELATIONSHIP

In T_2 each member of the triad directs a relation to one other member of the triad so that V_1 directs a relation to V_2, V_2 directs a relation to V_3, and V_3 directs a relation to V_1. This configuration describes a "cycle." As in the semicycle of T_1, all three members of the triad in

T_2 are connected by a line. The difference between T_1 and T_2 is that by tracing the direction of the relations, one can work around the triad and return to the original position. In T_1 this could not be done.

The eight basic triadic valence structures were developed without regard for the direction of relations (see Figure 5). Focusing only on the direction of relations reveals eight triadic directional structures. Two of the structures are cycles and six are semicycles. These eight directional structures fall into pairs, so that the two cycles go together as one pair and the remaining semicycles fall into three pairs. These triadic directional structures are presented in Figure 9.

Whereas the triadic valence structures reflect the valence of relations that a single actor maintains with each of two other actors and the valence of relations they maintain with themselves, the triadic directional structures reflect the direction of relations a single actor maintains with each of two other actors and the direction of relations they maintain with themselves.

The directional triads are classified further into four pairs. The first pair relates to cycles. Of that first pair, the first cycle, IA, "starts" with V_1 and passes through V_2 and V_3 in that order, while the second cycle, IB, "starts" with V_1 and passes through V_3 and V_2 in that order. The only difference in the two cycles is the "direction" in which they run.

There is a similar difference in the remaining pairs of semicycles, but in order to understand it one needs the help of the concepts of "reachability" and "path." If, in a digraph (a graph theory drawing such as we have been showing), there is a single line from one point to another, then the second point is reachable from the first along a path of "length one." Likewise, if, in a digraph, a second point is reachable from a first point, and a third point is reachable from the second point, then the third point is reachable from the first point along a path of "length two." Pictorially, a "length" is a line between two points. With these concepts in hand, the differences in the three remaining pairs of triadic directional structures that are not cycles can be clarified.

In the first remaining pair, IIA and IIB, it will be seen that there is a path of length two "starting" from V_1 in each case, with the dif-

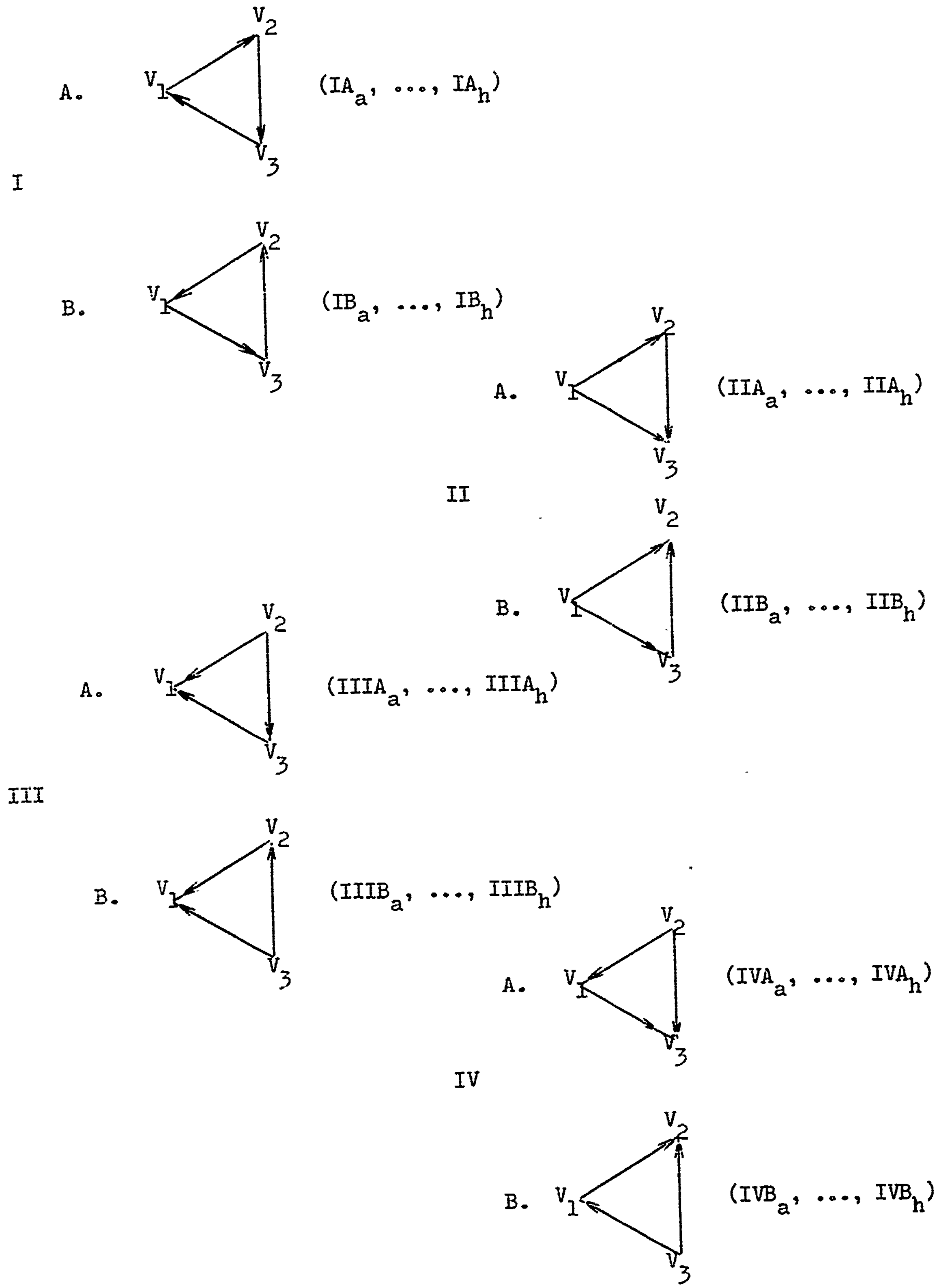


FIGURE 9: TRIADIC DIRECTIONAL STRUCTURES

ference between the two cases being (1) at which actor the two-path "terminates," and (2) through which actor it "passes." As a consequence of the different routes taken by the respective two-paths in IIA and IIB, the one-path required to close the semicycle "starts" from V_1 and "terminates" at different points in IIA and IIB respectively.

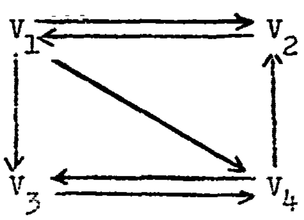
Understanding the differences between the triadic directional structures IIA and IIB should enable one to understand the differences between IIIA and IIIB, and IVA and IVB. In IIIA and IIIB, V_1 is on the "terminating ends" of a two-path and a one-path which start from different actors in each case. In IVA and IVB, V_1 is the "mid-point" along a two-path which "starts" from different points and goes in opposite "directions" in each case. The directions of the one-paths in IVA and IVB, as well as in IIIA and IIIB, and IIA and IIB, are dictated by the requirement that these triadic directional structures not be cycles.

Thus, eight different triadic valence structures, and eight different triadic directional structures have been presented. It should be obvious that each of the valence structures can assume any of the directional configurations, or, from the opposite perspective, each of the directional structures can assume any of the valence configurations. This gives a total of sixty-four balanced and unbalanced triadic structural possibilities among groups of three entities where directed relations are considered. The sixty-four possibilities are symbolized by the terms in parentheses accompanying each of the triadic directional structures in Figure 9.[11]

Having now developed a taxonomy of balanced and unbalanced triads, it needs to be shown how the triadic types may be found in a graph theoretical matrix of the type described on page 3. The proper term for such a matrix is an "adjacency matrix." Note that an adjacency matrix of international relations reveals whether one nation is adjacent to another nation in the sense that the first directs a relation to the second.

Thus far we have relied on graphic presentations to depict the relations among interacting entities. It needs to be demonstrated how the same information can also be contained in an adjacency matrix and, thus, be rendered machine readable as the discussion on page 3 indicated. Figure 10 illustrates this point. In Figure 10 a graph, G, has been shown which depicts a set of relations among four entities; the adjacency matrix, [A], that corresponds with G has also been presented.

In G it can be seen that V_1 directs relations to V_4, V_3, and V_2. Likewise, each of the other entities in the graph directs relations to at least one other member of the group. From a different perspective it can be seen that each member of the group "receives" at least one relation from other members of the group as in the case of V_4 which receives relations from V_1 and V_3.



	V_1	V_4	V_3	V_2
V_1	0	1	1	1
V_4	0	0	1	1
V_3	0	1	0	0
V_2	1	0	0	0

FIGURE 10: DIGRAPH G AND MATRIX [A]

The adjacency matrix [A] contains the same information as G. It can be seen that there is a row and a column in [A] for each entity in G, and that the row and column designations are paralled in the sense that Row 1 and Column 1 stand for entity V_1 of G, Row 2 and Column 2 stand for entity V_4 of G, and so on. Row entries in adjacency matrices reflect the existence of relations so that where a "1" appears in an ij cell it signifies that the entity designated as the i-th row directs a relation to the entity designated as the j-th column. Reading across the entries in Row V_1 it can be seen that V_1 directs relations to V_4, V_3, and V_2 and, looking back to G, it can be seen that these entries reflect the lines V_1V_4, V_1V_3, and V_1V_2 in G. Where the rows of [A] reflect the output of the members of G, the columns of [A] reflect the intake of members of G so that in Column V_4 there are entries at Row V_1 and Row V_3. That V_4 receives relations from V_1 and V_3 can be verified visually by examining G. The appearance of O's in [A] reflects the fact that no relation is present in G between the entities that correspond to the appropriate rows and columns of [A]. The total number of entries in [A] equals the total number of relations depicted in G.

The idea of an adjacency matrix can be expanded to incorporate positive and negative relations in specialized adjacency matrices so that an analyst may create an adjacency matrix that reflects the existence of positive relations only, A(P), or one that reflects the existence of negative relations only, A(N). In addition, a third matrix, A(S), which reflects the existence of both positive and negative relations, may be created. Thus, three specialized adjacency matrices are available.

Before proceeding further, let us give some attention to some other notions from graph theory that need to be incorporated. When an adjacency matrix is squared (i.e., multiplied by itself), the off-diagonal entries reveal how many paths of length two exist from the i-th row to the j-th column. That is, in a squared adjacency matrix where the i-th row intersects the j-th column, that entry reveals how many paths of length two run from i to j and pass through another actor in the matrix. So in $A(P)^2$ if $A(P)^2_{ij} = 3$ there are three paths of length two composed of positive relations running from i to j and passing through three other actors in the matrix. A similar case is $A(N)^2_{ij} = 3$, except the ij entry indicates the existence of three paths of length two that have two negative relations along which i can reach j.

When an adjacency matrix is squared, there is no need to think of a multiplier and a multiplicand so long as consistency is maintained throughout the multiplication operation. The opposite is true when two different matrices are multiplied. Here one must give regard to which matrix is the multiplier and which is the multiplicand so that in the present context, $[A(P) \times A(N)] \neq [A(N) \times A(P)]$. This fact can be applied usefully in the analyses of valenced structural matrices where if $[A(P) \times A(N)]_{ij} = 3$ it is known that there are three paths of length two from i to j in which the first relation is positive and the second is negative. Also, the fact applies in matrices where $[A(N) \times A(P)]_{ij} = 3$. It is known that there are three paths of length two from i to j in which the first relation is negative and the second is positive.

One more point about adjacency matrices needs to be emphasized. On page 3 the point was made that in an adjacency matrix the row entries represent an actor's output and the column entries an actor's intake. Thus by reading across rows it may be determined to whom an actor is adjacent, and reading down columns it may be determined from whom an actor is adjacent.

With the taxonomy and the graph theoretical tools that have been presented, the equipment is now ready for deriving the algorithms for finding balanced and unbalanced triads in a matrix composed of positive and negative relations. The complete set of algorithms totals thirty-two. Rather than presenting them all, we find it easier to present each of four general algorithms from which the thirty-two stem. Each of the four algorithms is a generalization about each of the four major directional types developed earlier and, as they are presented, an example of how they may be extended to find one of the thirty-two balanced or unbalanced triadic structures will also be included. If the reader has been following the discussion and understands the logic of the algorithms, he can develop all the necessary equations and adapt them to his own specific needs.

It might help the reader to know that these algorithms reveal in an adjacency matrix: (1) if any, and which of, the sixty-four specific triadic types exist in the matrix; and (2) which actors comprise those triads. Obviously, the capacity to provide totals, etc. is not built into the equations, but these capacities can be constructed into a computer program designed to monitor triads using the structural balance principle.

FINDING TYPE I TRIADS

If a point, V_1, can reach another point, V_3, along a path of length 2, and if V_1 is adjacent from V_3, then V_1 and V_3 are in a Type I cycle. Furthermore, under the above condition, any point, V_2, to which V_1 is adjacent and from which V_3 is adjacent, is in a Type I cycle containing V_1, V_2, and V_3.

Type Ia: $A(P)^2 \cap A(P)'$

$$\in [A(P)^2 \cap A(P)']_{ij} \neq 0, \; Ai(P)_{ij} \cap Aj(P)'_{ij}$$

(Note: $Ai(P)_{ij}$ should be read, "Reachable positive subset from i," and $Aj(P)'_{ij}$ should be read, "Positive subset from which j is reachable.")

FINDING TYPE II TRIADS

If a point, V_1, can reach another point, V_3, along a path of length 2, and if V_1 is also adjacent to V_3, then V_1 and V_3 are in a Type II semicycle. Furthermore, under the above condition, any point, V_2, to which V_1 is adjacent and from which V_3 is adjacent, is in a Type II semicycle containing V_1, V_2, and V_3.

Type IIg: $[A(N) \times A(P)] \cap A(N)$

$$\in \left\{[A(N) \times A(P)] \cap A(N)\right\}_{ij} \neq 0, \; Ai(N)_{ij} \cap Aj(P)'_{ij}$$

FINDING TYPE III TRIADS

If a point, V_1 is reachable from another point, V_2, along a path of length 2, and if V_2 is also adjacent to V_1, then V_1 and V_2 are in a Type III semicycle. Furthermore, under the above condition, any point, V_3, to which V_2 is adjacent and from which V_1 is adjacent, is in a Type III semicycle containing V_1, V_2, and V_3.

Type IIIc: $[A(P) \times A(N)]' \cap A(P)'$

$$\in \left\{[A(P) \times A(N)]' \cap A(P)'\right\}_{ij} \neq 0, \; Ai(N)'_{ij} \cap Aj(P)_{ij}$$

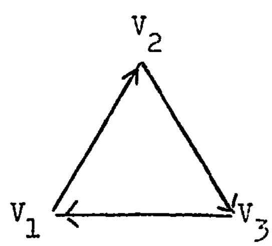
FINDING TYPE IV TRIADS

If a point, V_1, is adjacent from another point, V_2, and if V_1 and V_2 are both adjacent to a third point, V_3, then V_1, V_2, and V_3 are in a Type IV semicycle.

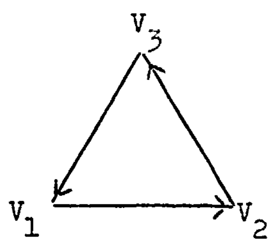
Type IVh: A(N)

$$\in A(N)'_{ij} \neq 0, \ Ai(N)_{ij} \cap Aj(N)_{ij}$$

These algorithms have been computer programmed to lift the burden of performing tedious matrix algebra operations from the analyst. Before presenting some output from the programs, we should consider one feature of the eight triadic directional types. For some of the computer operations the eight directional types have been reduced to two directional types: "Cycles" and "semicycles." The reader will recall that Type I triads are cycles, and Type II, III, and IV triads are semicycles. When presented diagrammatically, two major Type I cycles, Type IA and Type IB, emerge. The distinguishing feature of these two cycles is, in the first case, the direction of the relations "runs" clockwise while, in the second case, the direction of the relations "runs" counter-clockwise Structural matrices do not make this distinction as the following cyclical triads and their accompanying structural matrices illustrate.



	V_1	V_2	V_3
V_1	0	1	0
V_2	0	0	1
V_3	1	0	0



	V_1	V_2	V_3
V_1	0	1	0
V_2	0	0	1
V_3	1	0	0

FIGURE 11: TYPE I CYCLES AND THEIR STRUCTURAL MATRICES

In the first triad the direction of the relations is clockwise, and in the second triad the direction of the relations is counter-clockwise. Note, however, that the accompanying structural matrices are identical, which indicates that, for diagrammatical purposes, it makes little difference how triads are drawn so long as the from-to sequencing of nations is accurate.

In triadic cycles it is to be observed that each actor "receives" one relation and "sends" one relation. This is not so in triadic semi-cycles where one actor sends two relations, one actor both sends a relation and receives a relation, and one actor receives two relations. In terms of semicycles, generally, one need not be concerned with the specific types because in finding <u>any</u> semicycle its "sender-sender" actor, its "sender-receiver" actor, and its "receiver-receiver" actor will always be found. This is a useful generalization that can be made about triadic semicycles.

Of course, it does make a difference to think of the particular triadic types--whether cycles or semicycles--when the relations of a particular actor are being analyzed, or when the relations of a particular group of three actors are being analyzed. Obviously, it makes a difference in the role an actor plays in a particular semicycle whether that actor only sends relations, only receives relations, or both sends and receives relations. Similarly, it makes a difference whether an actor in any triad is adjacent to/from all positive relations, all negative relations, or both positive and negative relations.

For some purposes the analyst may want to explore a structural matrix for all of the taxonomic types, while for other purposes an abbreviated taxonomy may suffice. This principle has been incorporated in the inventory of computer programs we have developed. Some of the programs serve general needs, and others serve more specific needs.

AN INTERIM SUMMARY

To this point, the major theme of this paper has been that the relationship data in international event flows are just too complex and too interrelated to be handled efficiently except by thoroughgoing computerization. Graph theory is the vehicle for such applications. It is to be argued, of course, that graph theoretical techniques will not produce the same results as those provided by the expertise and the insights that some seasoned foreign policy experts have in some areas. The point is willingly granted. It is also to be argued, however, that in no way will any single foreign policy expert--or group of experts--ever be able to handle as many variables and their thousands of interrelationships as efficiently or as rapidly as graph theory operating in a standard monitoring procedure. Further, as stated earlier, graph theory is user-controlled for both the data it processes and for the way the techniques are chosen and applied.

Graph theory is a useful tool when incorporated in a system like the WEIS processor; it adds to the systematic and routine analysis of international relations and brings some sophistication and efficiency to the study of relationships that are imbedded in the data of international event flows.

In this paper, general means have been suggested through which graph theory can be usefully exploited in international studies. Possibly, the most useful of these is the notion of structural balance, central to which are the algorithms that are required to analyze a structural matrix for its triadic configurations. These algorithms are interesting. Many people have tried to provide the mathematical means for operationalizing the intuitively pleasing notion of structural balance. To our knowledge, no previous investigation has produced the algorithms presented here and the analytic breakthrough which they have facilitated.

A PILOT DEMONSTRATION

To demonstrate how the notion of structural balance can be used to analyze international relations we have chosen the situation that developed between the Palestinian guerrillas (PLO) and the Jordanian government (JOR) during September, 1970. In order to set the scene, we will review some of the major events that occurred just before and during that period.

June 12	JOR and PLO reached an uneasy peace agreement. . .periodic skirmishes between JOR and PLO continued.
August 7	UAR and ISR agree to a ceasefire along the Suez Canal.
August 12	News of UAR ceasefire violations appears in the New York Times.
August 26	JOR police and PLO guerrillas exchange fire in Amman.
September 6	PLO hijacks Pan Am jet to Cairo, and TWA and Swissair jets to Jordan.
	ISR withdraws from Middle East peace talks.
September 7	PLO blows up Pan Am jet in Cairo.
	Fighting between PLO and JOR escalates.
September 9	PLO hijacks BOAC jet to Jordan.
September 11	PLO begins releasing jet passengers.
September 12	PLO blows up jets.
September 18	Nasser appeals to PLO and JOR to stop fighting.
September 20	SYR ground forces invade JOR.
September 25-27	Nasser works out ceasefire agreement between PLO and JOR.
September 28	Nasser dies.
September 30	PLO withdraws from Amman.

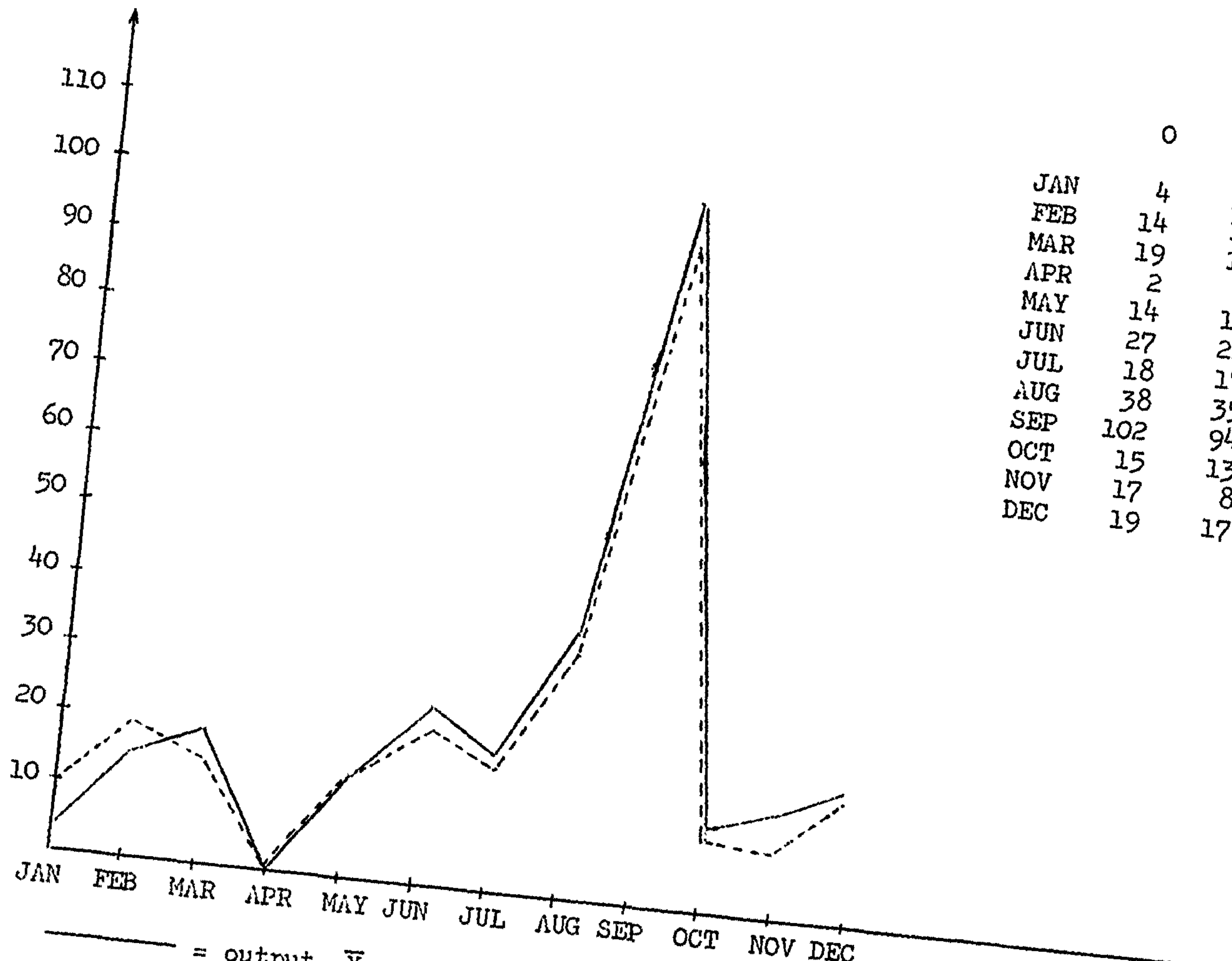
Now the question becomes: how might the WEIS processor and the notion of structural balance have been employed to anticipate th[illegible] situation, and to increase understanding of it? If the WEIS processor had been routinely monitoring nations' output and intake of event flows during 1970, quantitative shifts in PLO's total output and intake would have been detected during the month of August. These shifts went way beyond the mean deviation in the output and intake that PLO had been experiencing for the previous seven months. This fact is illustrated by Figure 12, which charts PLO output and intake for 1970. The shifts occurred against the background of the Suez Canal ceasefire and its subsequent "violation" by the Egyptians, and these shifts might easily have been overlooked by foreign affairs analysts who were preoccupied with Israeli-Egyptian actions. However, the WEIS z-score monitor would have prevented this from happening by automatically drawing attention to the deviation in PLO's behavior.

By focusing attention on the PLO, we proceed to the closer look at PLO relations. This entails several routine steps. The first step is to create a valenced adjacency matrix for the month of August that includes PLO and all of the countries in the Middle East action sphere that either were the targets of PLO action or themselves directed action to PLO. This matrix can be seen in Table 1.

	USA	IRQ	ISR	JOR	LEB	SYR	UAR	LBY	PLO
USA	0		1	1			1		
IRQ		0				1	1	1	1
ISR	1		0	-1	-1		-1		-1
JOR	-1	-1	-1	0			1		-1
LEB			-1		0		1		-1
SYR		1				0		1	1
UAR	-1	-1	-1	1	1	-1	0	1	1
LBY		1				1	1	0	1
PLO	-1	1	-1	-1	-1	1	1	1	0

TABLE 1: MIDDLE EAST ADJACENCY MATRIX FOR AUGUST, 1970

It will be recalled from previous discussions that this matrix contains underlying triads, some of which are balanced, and some of which



	O	I
JAN	4	10
FEB	14	19
MAR	19	14
APR	2	1
MAY	14	15
JUN	27	22
JUL	18	17
AUG	38	35
SEP	102	94
OCT	15	13
NOV	17	8
DEC	19	17

——— = output $\overline{X}$ = 21.50 (including September)

- - - - - - = intake $\overline{X}$ = 21.25 (including September)

FIGURE 12: PLO OUTPUT AND INTAKE FOR 1970

are unbalanced but, presumably, have a tendency to become balanced. The analyst needs to know which of the triads in this matrix are the salient ones, and are, thus, most subject to the conditions of structural balance. He will note that by the end of August, PLO's most salient interaction partner was JOR. From this information, he identifies the two actors whose relations will form one side of the triadic structures that are of interest to him.

The next step will be to find all of the third parties that form closed triads with the PLO-JOR dyad, in the sense that the PLO-JOR dyad directs two relations to the third nation, or they each receive relations from the third nation. This information is provided by the four structural balance programs, i.e., NOVAL, DATA, CYCLES, and SEMICY; however, for the demonstration we present this information graphically:

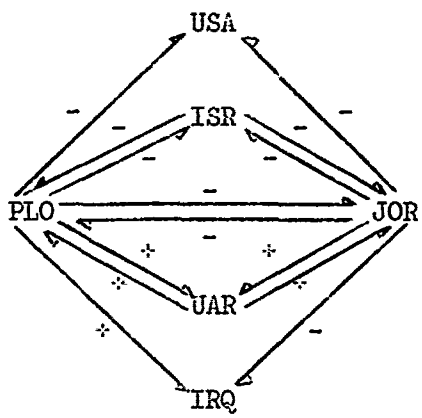


FIGURE 13: MIDDLE EAST TRIADS, AUGUST 1970

Next, the problem is to find all of the third parties who in August were maintaining relations with either PLO or JOR, and who had the potential for becoming members of closed triads with PLO and JOR provided that the situation should continue to develop into September. This information is also presented graphically:

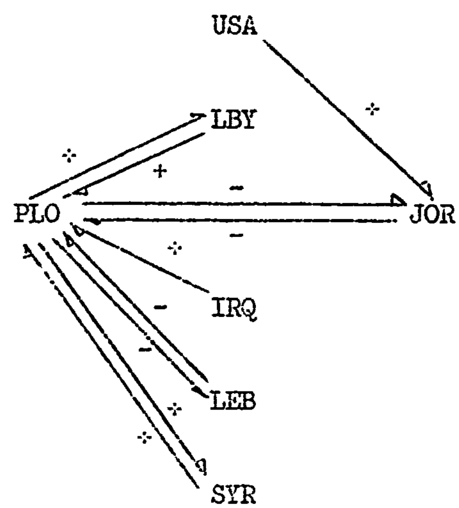


FIGURE 14: POTENTIAL MIDDLE EAST TRIADS, AUGUST 1970

Given the foregoing information one can say more about how the interaction matrix will look in September. Of the closed triadic structures presented in Figure 13, only one is balanced; the rest are unbalanced. Thus, it can be predicted that the unbalanced closed triads found in August will become balanced in September. A similar prediction can be made about the potentially closed triads: if they become closed in September they will do so in a balanced fashion.

The expected valenced relations may be compared against the actual data for September, as presented in Table 2. Notice that the adjacency matrix for September is larger than the one for August. This is due to the fact that as the PLO-JOR conflict escalated, more nations became involved. The same criterion of taking all the countries that either received one relation or directed one relation to PLO and/or JOR was used to construct the September matrix.

Again, for demonstration purposes, we present graphically the closed triadic interaction structures contained in the September matrix (Figure 15).

In Figure 13 there were unbalanced triads involving the principal combatants and USA, ISR, and UAR as third parties. In Figure 15, it

	USA	USR	IRQ	ISR	JOR	LEB	SYR	UAR	LBY	SUD	PLO
USA	0	1	-1	1	1		-1	1			-1
USR	-1	0	1	-1	1		1	1			1
IRQ			0		-1						1
ISR	1	-1		0	-1	-1		-1			-1
JOR			1		0		-1	1	1	1	-1
LEB	-1			-1		0					1
SYR	-1				-1		0	1	1		1
UAR	-1	1		-1	-1		1	0	1	1	1
LBY					1		1	1	0		1
SUD					-1			1		0	1
PLO	-1		1	-1	-1			-1		1	0

TABLE 2: MIDDLE EAST ADJACENCY MATRIX, SEPTEMBER 1970

can be seen that USA no longer receives relations in an unbalanced triad; instead, USA directs relations in a balanced triad. In addition, ISR no longer receives relations in an unbalanced triad; however, ISR continues to direct relations in an unbalanced triad. UAR, as indicated in Figure 15, both directs relations in a balanced triad, and receives relations in a balanced triad. Of the potential triads depicted in Figure 14, all of those that closed in Figure 15 closed in a balanced fashion.

In Figure 15 some unbalanced triads exist, but to say that they detract from the usefulness of the technique being demonstrated would not be accurate since these unbalanced triads are shown to exist on the basis of one event, or their relations are assigned valences on the basis of an ambiguous event mixture. Also, considering the fact that we are

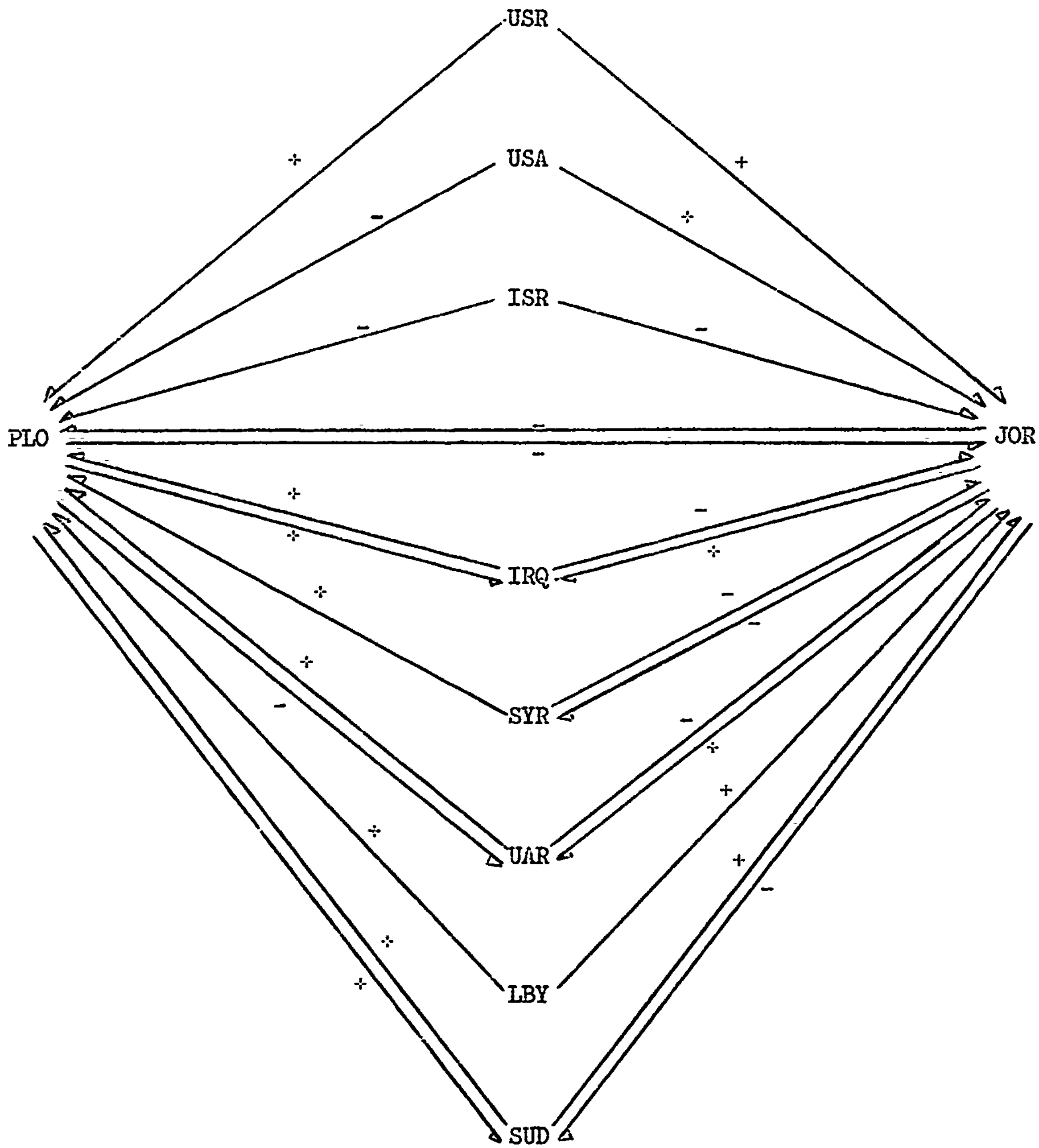


FIGURE 15: MIDDLE EAST TRIADS, SEPTEMBER 1970

operating with a data source that is not as complete as possible, we are quite pleased with the outcome of this demonstration.

We feel that we have successfully shown how graph theory and the notion of structural balance can be used to monitor, understand, and project international event flows. Without going into too much detail about Middle East relations, a demonstration has been presented in which most of the interaction linkages conform to the notion of structural balance. To recount, we have:

(1) detected an early shift in event flows (this is a criterion stated in the WEIS processor for recognizing salient features in the monitored materials);

(2) constructed the adjacency matrix of relevant relations;

(3) performed a computer analysis;

(4) charted the pattern of friendly and unfriendly relations; and

(5) used the principle of structural balance to understand a developing situation and make accurate predictions about its future state.

REFERENCES

1. The author who has devoted much of his talent to summarizing and developing the mathematics of graph theory is Frank Harary. See Frank Harary, Robert Z Norman, and Dorwin Cartwright, Structural Models: An Introduction to the Theory of Directed Graphs. New York: John Wiley and Sons, Inc., 1965, and Frank Harary, Graph Theory. Reading, Mass.: Addison-Wesley, 1969.

2. The "WEIS processor" is a set of automated statistical techniques designed to analyze incoming information about international relations such as the event data culled from the New York Times by the World Event/Interaction Survey. On the basis of the pattern of incoming information, the WEIS processor makes short term projections about the state of international relations. The WEIS processor is summarized in the 1970-71 WEIS annual report, and it is from the report that this paper has been adapted. See Charles A. McClelland et al.: The Management and Analysis of International Event Data: A Computerized System for Monitoring and Projecting Event Flows (Los Angeles, California: School of Politics and International Relations, University of Southern California, September 1971).

3. A more detailed explanation of INTSCAN may be found in Charles A. McClelland, et al., op. cit., pp. 93-124.

4. At this point in a discussion of graph theory one has the option of becoming highly technical and mathematical, or of remaining less technical and verbal. Sacrificing the economy and specificity of mathematics, this present discussion remains in the verbal mode.

5. John Sigler, formerly with the Department of State and now a member of the academic community, has found that during the 1967 Middle East Crisis dramatic interaction shifts occurred whereby Egypt increased its interaction with other Arab countries and Israel increased its interaction with European countries. See his "Information Processing in an International Crisis: Egypt and Israel in the June War," (mimeo). Paper presented to the Annual Meeting of the Middle East Studies Association (M.E.S.A.), November, 1970.

6. A more complicated structural monitoring technique that reveals interaction groupings and alliance structures has been developed and explained in Ronald G. Sherwin and Nien-Ling Wayman, "Faster Matrix Clustering: An Improved Technique for Solving Matrix Clustering Problems," (Los Angeles, Calif.: University of Southern California (WEIS), November 1971); and Ronald G. Sherwin, "Interaction Sub-groups in the International System," (Los Angeles: University of Southern California (WEIS), forthcoming).

7. This notion was first suggested for use in the analysis of international relations by Frank Harary. See "A Structural Analysis of the Situation

in the Middle East," Journal of Conflict Resolution, 5,2 (June 1961), 167-178. See also, Patrick Doreian, "Interaction Under Conditions of Crisis: Applications of Graph Theory to International Relations," Papers, Peace Research Society (International), XI, 1969, pp. 121-153. The notion of structural balance was first stated by Fritz Heider. See his "Attitudes and Cognitive Organization," Journal of Psychology, 21, 1 (January 1946), 107-112, or The Psychology of Interpersonal Relations, New York: John Wiley and Sons, Inc., 1958. The notion was re-worked to apply strictly to inter-actor relations by Dorwin Cartwright and Frank Harary in "Structural Balance: A Generalization of Heider's Theory," Psychological Review, 63, 5 (September 1956), 277-293.

8. The theory behind SCALOR is complex, but its practical use has proven successful and intuitively pleasing. From the standpoint of its being able to support empirically operationalized statements about the affective distances between nations, SCALOR will no doubt be as successful as other attempts to scale international event data. See Herbert L. Calhoun, "The Semantic Differential: An Approach to the Measurement and Scaling of International Event Data" (unpublished Master's Thesis). Los Angeles: University of Southern California, 1971. See also Calhoun, "The Measurement and Scaling of Event Data Using the Semantic Differential," (Mimeo). Paper presented to the 25th Annual Meeting of the Western Political Science Association, April 1971.

9. The programs have been developed with the technical help of Gary Klein from Jet Propulsion Laboratories, Pasadena, California.

10. The list of sociologists, social psychologists, statisticians, and mathematicians who have attempted to do this is long. The most systematic and most nearly successful attempts have been carried out by James A. Davis, "Clustering and Structural Balance in Graphs," Human Relations, 20,2 (May 1967), 181-187; Frank Harary, "On the Measurement of Structural Balance," Behavioral Science, 4, 4 (October 1959), 316-323; Harary, Norman, and Cartwright, Structural Models, Chapter 13, pp. 339-362; and Paul W. Holland and Samuel Leinhardt, "A Method for Detecting Structure in Sociometric Data," American Journal of Sociology, 76, 3 (November 1970), 492-513.

11. The taxonomy developed in this paper exhausts the possibilities for triads composed of unilateral relations. Obviously, triads may also be composed of bilateral relations or combinations of bilateral and unilateral relations. The number of combinations of triadic structural possibilities in a fully developed taxonomy under these conditions is immense, and beyond the scope of this introductory paper. For the fully developed taxonomy, see Ronald G. Sherwin, "A Taxonomy and the Required Algorithms for Operationalizing the Notion of Structural Balance," (Los Angeles: University of Southern California (WEIS), forthcoming).