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Discrete Sequence Rule Models as a Social Science Methodology: An Exploratory Analysis of Foreign Policy Rule Enactment within Palestinian–Israeli Event Data

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Existing formal models of political behavior have followed the lead of the natural sciences and generally focused on methods that use continuous-variable mathematics. In 2002, Stephen Wolfram produced an extended critique of that approach in the natural sciences, and suggested that a great deal of natural behavior can be accounted for using rules that produce discrete patterns. This paper reports some initial findings designed to apply this pattern-based method to political event data. We believe that discrete sequence rule (DSR) models can provide a new social science methodology that is capable of preserving the agential basis of social interaction, tracking multiple agents as they enact rules through behavior directed at one another, and capturing the evolution of such interaction over time. The core of this project is a new, publicly accessible Web-based tool designed for the visualization and analysis of event data patterns (http://www.nkss.org). Using event data on the Israel–Palestine conflict generated by the TABARI automated coding program of the Kansas Event Data System (KEDS) for the period 1979–2004, we perform an initial exploration of this methodology. Specifically, we identify patterned behavior for which specific rule use can be imputed, and then examine several agent-based rules, plus four "meta-rules," to parse Israeli–Palestinian interaction over time. Face validity of the analysis is apparent, and we also find the qualitative historical record can be augmented through observation of rule enactment in the event stream. Several descriptive empirical applications are demonstrated, including moving totals and increasingly complex sequences of rule enactment that go beyond the simple variations on tit-for-tat responses. While this paper represents an exploratory analysis of the method, the results are promising enough to warrant further investigation beyond its use in thick description as demonstrated here, to ultimately include hypothesis generation and falsification.

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For the past 2 centuries, the social sciences have aspired to produce law-like generalizations about human behavior comparable to those found in the deterministic study of mechanics in Newtonian physics or the probabilistic models found in epidemiology. Unsurprisingly then, social science has embraced the view that ''the stature of a science is commonly measured by the degree to which it uses mathematics'' (Weinberg 1975:264). Considerable scientific work has been done over the past 60 years in our field of research, international relations and foreign policy (IRFP), but this effort has produced virtually no law-like generalizations, and what few might be said to exist give us almost no mileage beyond what common sense already provides (Bull 1966; Gaddis 1992; Green and Shapiro 1995; Walt 1999; Bennett and Stam 2004). These conclusions, we believe, can be applied to social science more generally, as well.

Indeed, a deep-seated methodological discontent is growing in IRFP, in political science, in economics, and in other social sciences. The most ''advanced'' methods we can use seem to fit poorly with the types of questions we would like to answer. The more esoteric our fields become methodologically, the more removed from reality and the more irrelevant to pressing human concerns the research seems to become. The Post-Autistic Economics Movement in economics (http://www.paecon.net/) and some aspects of the Perestroika Movement in political science (Monroe 2007) are but two recent manifestations of the yearning of social scientists, especially young social scientists, to move beyond what is perceived to be the increasing disconnect of their respective fields (see Hogarth and Reder 1987; Fullbrook 2001; *PS* 2003 special issue July 2003).

Yet the alternative methodological standpoints most often articulated frequently propose to refocus social science research on in-depth case study, history, constructivism/discourse analysis, or nihilistic postmodernism, and thus seem to have similar potential for controversy and paralysis. The issue here is falsifiability and its relationship to causality (Yee 1996). Unless some concept of a causal link is maintained in a methodology for the study of human behavior, it seems difficult to assess the validity of a particular historical or constructivist account. And since the findings of the social sciences aim to inform social practice and policy, which may have profound impact on the lives of individuals, some minimal falsifiability seems morally imperative. It may even be theoretically imperative as a marker between justifiable and unjustifiable interpretations of social phenomena.

In 2002, a methodological gauntlet was thrown done by Stephen Wolfram in his work, *A New Kind of Science*. Though his book was not written from or for a social science perspective, several of his assessments are pertinent to that endeavor. Wolfram asserts that most modern scientific methods used in the physical and biological sciences are but idiosyncratic and limited derivations from something much more basic, more fundamental, and more powerful. In place of the continuous-variable mathematical structures that underlie classical mechanics and statistics, Wolfram's approach focuses on the discrete transformation of rule-based patterns. Simple rule-based pattern models can, through iteration, produce surprisingly complex behavior in physical and biological systems. For example, in biological systems, the patterns in the amino acids coded by a strand of DNA combine to produce the patterns formed by collections of proteins, which in turn produce structures in cells which themselves interact, as do combinations of the cell, and so forth to ever-higher levels of complexity. Although the initial patterns in the DNA are very simple, they can ultimately produce highly complex organisms, including human beings.

Conveniently for social scientists, humans not only originate from patterns, but human psychology is intensely linked to the ability to perceive patterns and to find meaning in patterns (Newell and Simon 1972; Abelson 1973; Simon 1982; Anderson 1983; Kohonen 1984; Holland, Holyoak, Nisbett, and Thagard

1986; Margolis 1987; Khong 1992; Reber 1993; *Political Psychology* 2003). Indeed, it is not far off the mark to suggest the ultimate basis of all human epistemology is *discrete pattern identification.* As Wolfram puts it, ''observers will tend to be computationally equivalent to the systems they observe,'' (Wolfram 2002:737) an observation we will explore shortly.

Most of our existing formal methods in IRFP take a strictly arithmetic view of allowable interactions and usually involve a simple quantitative definition of all elements of understanding: models involving the analysis of interval-level variables are substantially more developed than those involving nominal-level variables. For example, most contemporary analyses of nominal variables use either dummy variable regression (nominal independent variables) or variations on logit analysis (nominal dependent variables). Both techniques are essentially mathematical tricks for treating the nominal variables as if they were interval, and their estimation is performed entirely in the domain of continuous variables.

Simple introspection will show that many interactions in the world have no counterpart in continuous-variable operations, nor can we define every concept in terms of quantities. As Wolfram puts it, ''it is in many cases clear that the whole notion of continuity is just an idealization—although one that happens to be almost required if one wants to make use of traditional mathematical methods.'' (Wolfram 2002:729). The non-continuous nature of much of social reality is why we employ human diagnosticians, intelligence analysts, and police detectives. As rule-based pattern recognition devices, our own brains are more powerful—and typically utilize quite different mechanisms—than the most sophisticated mathematical and statistical methods, and at a deep level, we realize this fact anew every time we read a piece of qualitative research in the social sciences.

Mathematical and statistical approaches are a tiny and quite restricted subset of what the human brain is able to bring to bear on a subject matter in pursuit of understanding. This is not to say those approaches are not useful—they are very useful, particularly in realms involving large samples, high levels of noise, and variables that can be naturally operationalized using continuous measures. But they are elementary methods compared to what we already know how to do. As Wolfram puts it, ''the field of mathematics as it exists today will come to be seen as a small and surprisingly uncharacteristic sample of what is actually possible'' (Wolfram 2002:821).

Humans were built to make sense of complexity. In a sense, the way to move past the methodological discontent in our social science disciplines may be to discover more about how our minds in fact do this. ''How we do this'' is certainly the foundation of mathematical and statistical approaches, but that foundation could support a much more varied set of methods. If we can explore that ''more,'' we will give ourselves more powerful and less constrained methodologies specifically geared towards the understanding of complexity.

Not only are individual humans built to make sense of complexity by the use of pattern recognition and rule-based behavior, many of the computational modeling projects in political science (Carbonell 1978; Thorson and Sylvan 1982; Sylvan and Chan 1984; Majeski 1987; Andriole and Hopple 1988; Sylvan, Goel, and Chandrasekran 1990; Hudson 1991; Mefford 1991) have justifiably assumed that human collectives, including national bureaucracies do so as well. Because of the rule-oriented nature of bureaucracies and the simplifications inherent in popular ideologies, one should be able systematically to extract an organization's rules and precedents from a sufficient quantity of debates, formal regulations and internal memoranda, and from these rules one could simulate much of the governmental decision-making process. The qualitative literature, for example Cyert and March (1963) and Allison (1971), has also long emphasized the rule-based nature of organizational decision-making. In much of their behavior, the bureaucracies are not acting *as if* they followed rules; they are instead *explicitly* following rules and are expected to do so, rule-following being a *sine qua non* of bureaucratic behavior. Thus, the rule-based pattern approach to social science is applicable not only at the level of individuals, but also at the levels of the groups, organizations, and bureaucracies which are the focus of much of foreign policy analysis.

Since human understanding involves matching observed events to a rule-based pattern, the function of political discourse is to provide sufficient information to cause the audience to understand (i.e., pattern match) the situation in the same manner that the individual or collective transmitting the information understands it. Political information transfer is the attempt to stimulate pattern recognition in the mind of the audience and thereby trigger a desired behavior. This process can occur between competing organizations as well as within them, and, in democratic situations, in how an organization explains itself to the public. Signaling in a conflict situation involves exchanging messages with an opponent in an attempt to get the opponent to undertake, or refrain from undertaking, certain actions. Consequently we would expect to see in political behavior and its accompanying discourse, the explicit use of, and reference to, specific patterns of behavior instantiated in sequences of individual events from which rules—and hence intentions and purposes—can be inferred. As a consequence we are calling these ''discrete sequence rule models,'' or DSR models.[1] This is a much more intuitive approach to social science explanation than is currently possible using standard statistical–mathematical techniques, and it is an approach that preserves, rather than obliterates, the agential nature of social interaction.

Visualizing Discrete Sequence Rules

Though the human cortex is adept at identifying patterns through the five senses, there is no doubt that the most advanced pattern recognition sense of *Homo sapiens* is sight. A powerful way of examining social phenomena, then, would be a method allowing visual inspection of that data for patterns. In order to visualize event data streams and the discrete sequence rules within those streams, we have developed the EP (Event Patterns) Tool, a Web-based methodology that permits recoding of data, visualizing of events, and imputation of agent-based rules for interaction. EP Tool currently resides at http://www.nkss.org. That site includes a number of data sets from the Kansas Event Data System (KEDS) project, and provides several well-documented facilities for recoding the data, specifying rules, and visualizing event data as discrete patterns rather than scaled aggregations. In particular, the inputs titled ''patterns'' and ''display'' allow a researcher to perform discrete pattern transformations on the graphic output. One can also experiment with hypothetical rules, then display whether those patterns account for any of the behavior in the set.

EP Tool differs significantly from existing sequence-analysis tools such as Bakeman and Quera's GSEQ (Bakeman and Quera 1995; Bakeman, McArthur, and Quera 1996a; Bakeman, Robinson, and Quera 1996b, http://www.ub.es/comporta/sg.htm) in two respects. Most importantly, the EP Tool is designed for the specification and visualization of very complex rules that aggregate diverse behaviors, whereas GSEQ and most other tools designed for the study of individual interactions are focused on relatively simple, discrete behaviors, such as the reactions that a mother might have to a crying baby (one of Bakeman and Quera's examples). Second, GSEQ is firmly developed in a statistical framework, and designed to implement an assortment of nonparametric statistical tests, whereas the EP Tool uses a rule-based framework. While it is possible to look at

[1] In a sense, then, we aim to implement *reverse* Wolfram modeling. Where Wolfram would posit rules and then observe resulting patterns, we are observing patterns that are the result of rules and we intend to postulate what those rules are, and ultimately subject those postulations to efforts at falsification.

those rules in the context of probability theory—as we have done in Schrodt and Hudson (2006)—our primary focus in this article is the use/non-use of rules as instantiated in event data.

DSR Exploration

In our first exploratory experiments with DSR modeling using EP Tool, we have used it as a means to provide thick description of the signaling taking place between a dyad of nations. By examining what we are able to ''see'' in this initial exploration, and whether what we see has face validity, we will then be in a position to move beyond description to hypothesis generation and falsification in subsequent efforts. In this first exploration, then, we have specified some very simple rules, starting with the widely researched tit-for-tat (TFT) pattern of interaction, and then ascertained how well they accounted for the behavior in the Israel–Palestine dyad. We chose this dyad because it is highly active and has been the focus of sufficient media attention that we can be confident that the event data are a reasonably accurate description of the actual behavior in the system. Furthermore, event data on Israeli behavior has been analyzed using a variety of techniques, including vector autoregression (Goldstein, Pevehouse, Gerner, and Telhami 2001; Sprecher and Derouen 2002), binary cross-sectional general estimating equations (DeRouen and Sprecher 2006), time-series cluster analysis (Schrodt and Gerner 2000), and event history models (Schrodt and Gerner 2004) and has generally produced credible results. The dyadic relationship between the Israelis and Palestinians, while certainly affected by the initiatives of third parties, is nevertheless quite internally reactive, as many scholars have noted (see for example Gerner 1994; Tessler 1994; Bickerton and Klausner 1998; Gauss 1998).

The next step in our analysis was to devise a set of interaction rules whose use could be investigated. Wolfram himself provides encouragement that the rules need not be many, and neither do they need be complex: ''Simple and definite underlying rules can produce behavior so complex that it seems free of obvious rules'' (Wolfram 2002:752). Indeed, Wolfram found that the most complex behavior could be obtained with sets of approximately three rules. We feel that there is reason to believe that the set of rules being employed by the Israelis and Palestinians in enacting what they feel to be meaningful behavior toward one another is also not very large, nor very complex. Signaling between organized human collectives, especially those in conflict, almost mandates that only a small set of simple rules be used in order to maximize the chances that the other group will understand the meaning intended by the action.

Furthermore, because international politics is a complex problem-solving environment, heuristics—simple rules used to partially solve complex problems—are of particular importance. Purkitt observes:

> To cope with limited cognitive capabilities, individuals selectively process information and use a limited number of heuristics or mental rules of thumb as cognitive aids in their effort to manage information. This apparently universal reliance on intuitive heuristics to solve all types of problems seems to be due to the need to compensate for the limitations of short-term memory and information processing capabilities. By using intuitive mental heuristics, people can develop a problem attack plan which permits them to develop a subjectively acceptable problem solution. (Purkitt 1991:43)

For example, rational choice and balance of power theories are heuristics in the sense that they are relatively simple; they come with a complex set of side-conditions, and they are intended as general rules to guide decision-making without providing a complete specification of actions to be taken. To the extent that an heuristic is shared by the decision-makers in a political system—for example balance of power in 19th century European diplomacy or the Chicken game in 20th century nuclear deterrence—it reduces uncertainty and becomes self-validating.

For our initial explorations of the DSR method, we selected a set of rules that we believed were enacted between the Israelis and Palestinians on an aggregate level. These rules were chosen from a combination of the general theoretical literature and a qualitative assessments of what some experts in the field assert are the rules these specific actors do use (e.g., Gerner 1994; Tessler 1994; Bickerton and Klausner 1998; Gauss 1998; Goldstein et al. 2001). These rules, like those of any formal model, constitute a simplification of the actual behavior driving the event-generating process.

We did impose some delimiting assumptions in our use of DSR models. First, following the practice of most of the quantitative literature in the field, we are treating both sides as unitary actors, despite the fact that behavior by the Palestinians in particular is quite decentralized, notably in the oftentimes divergent agendas of the generally secular Fatah movement and the Islamic militant groups such as Hamas. There is no necessity in the DSR method to take this approach, but it simplified our experiments at this initial exploratory stage. Furthermore, there is reason to believe—and this contention is supported by earlier empirical work in various statistical frameworks—that there is sufficient consistency at the aggregate level to find some patterns even with this rough assumption. Second, we examined a simple dichotomy of conflict behavior and cooperative behavior, though that, too, is not demanded by the model, and KEDS data can support behavioral distinctions of very fine grade.

Tit-for-Tat

The first rule we used was the classic TFT approach immortalized by Anatol Rapoport and, more recently, Axelrod (1984). Country experts have asserted that the Israelis and Palestinians consciously use this rule; and it has long been known that reciprocity is one of the strongest patterns in event data (e.g., Dixon 1986; Goldstein and Freeman 1990; Ward and Rajmaira 1992; Goldstein and Pevehouse 1997). We examined both TFT conflict and TFT cooperation episodes in the data.

Non-Tit-for-Tat (Provocation/Olive Branch)

Delineating TFT exchanges also enabled us to examine a second subset of rules—non-tit-for-tat (NTFT) interactions, where one side will offer conflict in a fairly peaceful context (what we term ''provocation''), or cooperation in a fairly conflictual context (what we term ''olive branch''). The olive-branch rule is the standard gambit for breaking out of the mutually destructive DD/DD/.../DD sequence in the classical prisoners' dilemma game. Provocation, of course, is its complement in escalation away from a CC/CC…/CC sequence.

Pause

Third, we examined the strategic use of non-action, or what we term ''pause.'' Pauses make communication more intelligible, especially in interaction contexts characterized by considerable noise. Pause is often used to accentuate what action is taken after the end of the pause, because the non-action sets the subsequent action apart from the continual give-and-take of the unfolding relationship. It can also be used to signal the sincerity of a change in policy that follows the pause, because action after a pause is scrutinized more carefully.

Meta-Patterns

Finally, we looked at four more complex ''meta-patterns'' that involved patterns-of-patterns—that is, complex patterns that were built out of the occurrence of simpler pattern. These meta-patterns are ''state'' variables that characterize the status of the dyadic relationship. We delineated four meta-rules that would produce distinct patterns: one-sided conflict, mutual conflict, mutual cooperation, and cooperation/conflict combined.

A summary of the rules examined in this initial analysis is provided in Table 1.

Empirical Investigations

Characterization of the Israel–Palestine Event Data Used

News reports on the interactions between Israel and Palestine were coded into the WEIS scheme (McClelland 1976) using TABARI.[2] The events were coded from Reuters News Service lead sentences obtained from the NEXIS data service for the period April 1979 through May 1997, the Reuters Business Briefing service for June 1997 through December 1998, and *Agence France Presse* from January 1999 to December 2004.[3] The data were run through a ''one-a-day'' filter to

TABLE 1. Rules Examined in the Initial Empirical Analysis

Name of Rule or Meta-Pattern	*Characterization of Rule*
TFT conflict	Tit-for-tat conflict; above-threshold material conflict on one side followed by above-threshold material conflict on the other
TFT cooperation	Tit-for-tat cooperation: above-threshold material cooperation on one side followed by above-threshold material cooperation on the other
Provocation	Non-tit-for-tat material conflict: no above-material conflict on the one side, followed by above-threshold material conflict on the other side
Olive branch	Material cooperation by one side, preceded by material conflict on the other side
Pause	Material cooperation followed by below-threshold material conflict on one side, which was preceded by above-threshold material conflict on the other side
Meta-pattern: asymmetric conflict (Code Red)	No material cooperation from either side; only one side is expressing material conflict
Meta-pattern: mutual conflict (Code Black)	No material cooperation from either side; both sides are expressing material conflict
Meta-pattern: mutual cooperation (Code Yellow)	No material conflict from either side; both sides are expressing material cooperation
Meta-pattern: mixed cooperation and conflict (Code Purple)	Material conflict from either or both sides and material cooperation from either or both sides

[2] Discussions of machine coding can be found in Gerner, Schrodt, Francisco, and Weddle (1994), Schrodt and Gerner (1994), Huxtable and Pevehouse (1996), and Bond, Craig Jenkins, Taylor, and Schock (1997), Subramanian and Stoll (2004); King and Lowe (2004); and Schrodt (2006). While the analyses in this paper use the WEIS coding scheme, in the near future we will be switching the project over to the new CAMEO framework (Gerner, Schrodt, Yilmaz, and Abu-Jabr 2002), which is optimized for automated coding.

[3] The second analysis is done with an older version of the KEDS Levant data set where the Reuters to AFP transition occurs in October 1999. In the process of working on this paper, we discovered that some of the 1999 data in this set were based on a set of texts that under-represented Israel–Palestine events; subsequent work will be based on the corrected set.

eliminate duplicate reports of the same event by allowing only one instance of any source-event-target combination in a day. As noted below, we used two different actor coding configurations—these will be discussed in the sections on the individual applications. The coding software, coding dictionaries and data are available at the KEDS Web site, http://web.ku.edu/keds.

For the event counts, we use the following categories based on the WEIS two-digit cue categories:

> material cooperation: WEIS categories 01, 06, 07
> verbal cooperation: WEIS categories 02, 03, 04, 05, 08, 09, 10
> verbal conflict: WEIS categories 11, 12, 13, 14, 15, 16, 17
> material conflict: WEIS categories 18, 19, 20, 21, 22

This reduces the number of distinct event categories that can be used in the patterns to a manageable size and eliminates the problem of three-digit WEIS categories that have very low frequencies. It is also likely to reduce the effects of coding error somewhat: Several of the ''verbal conflict'' codes in WEIS are ambiguous even for human coders, and the automated coding probably generates some misclassification within those categories.

Application 1: Graphic Representation of Raw Events

One obvious application of this approach is the visualization of raw events data in a symbolic form that the mind can be trained to understand. Such a technique is very useful for data exploration and abduction at the early stages of analysis. In the display in the Web-based Figure 1 (http://nkss.org/fpa/figure.1.htm),[4] we see simple material conflict data for the autumn of 1995; the Palestinian material conflict behaviors are to the left and pointing left, and the Israeli to the right pointing right. Each succeeding row of symbols corresponds to a sequential 2-day period of time; thus the top row corresponds to late September, and by the bottom of the display, we are in late October.

The Web-based Figure 2 (http://nkss.org/fpa/figure.2.htm) provides a view of material conflict and material cooperation simultaneously: the solid green squares on the left are Palestinian material cooperation behavior, and to the solid blue squares on the right are Israeli material cooperation behavior. The time period pictured is early 2001, just after the outbreak of the second *intifada.* Notice that this period is characterized not only by an upsurge in violence, as expected, but it is also characterized by repeated instances of limited material cooperation on each side, which is not part of our conventional view of the period. Any event categorization scheme conceptualized by the researcher, no matter how complex, can be made into a visual display by EP Tool.

While examination of the raw data in chronological visual view is a natural starting point, the most intuitive next step is to specify rules governing the interactions that we are seeing in these raw data displays, and then examine their patterns of enactment. It is to that subject we now turn.

Rules and Thresholds

In this initial analysis, we focus on material conflict and material cooperation, as distinct from verbal interaction, with the rationale that actions do indeed speak louder than words in the intractable Israeli–Palestinian conflict. The most salient signaling should be through material action, not verbal rhetoric, and

[4] An index to all of the Web-based figures used in the paper can be found at http://nkss.org/fpa/index.html Figures have been checked for proper appearance in the Microsoft Explorer, Mozilla Firefox and Apple Safari browsers.

consequently we would expect the patterns to be more distinct in that domain of behavior.

As we experimented with the rules, it became clear that we would need to establish thresholds of conflict for such operational definitions of rule enactment. Specifically, there is chronic conflict in the Israeli–Palestinian dyad, and it is necessary to distinguish between this ''background noise'' of constant material conflict and any new signals that might indicate a change in the pattern of conflict. From the graphic representation of raw events, we induced a threshold of four Israeli material conflict events in a 6-day period below which no signaling would be apparent to the other side; and for the Palestinians, a threshold of two material conflict events in a 6-day period would distinguish background noise from signal. Material cooperation was sufficiently rare in the interaction data that no threshold was set for those events.

Given these thresholds, coding of the rules in Table 1 was fairly straightforward. For example, TFT conflict rule enactment for, say, the Israelis, would ''fire'' if the Israelis exceeded their material conflict threshold in the current time period where the Palestinians had exceeded their material conflict threshold in the prior time period. Olive branch would ''fire'' for Israel if the Israelis had engaged in material cooperation in the current period where the Palestinians had exceeded their threshold for material conflict in the previous time period. Specification of time periods can be adjusted by the researcher: we used a standard time period of 8 days' duration for this exercise. It is important to remember that a rule ''fires'' and its symbol appears in the display, when the *rule has been fulfilled.* This means that the symbols for rule enactment appear with a rule-specific lag in the visual displays; one must look *before* the appearance of a rule symbol for the behavior that caused it to appear.

Figure 3 (http://nkss.org/fpa/figure.3.htm) shows the almost continuous occurrence of the TFT conflict rule—the solid red squares—on both sides in the first months of the first *intifada*; this is characteristic of the conflict during both the first and second *intifadas.* Note also that because there were also a few incidents of material cooperation during this period (solid green squares for the Palestinians; solid blue squares for Israel), the olive branch pattern (gold solid triangle) is also occasionally triggered. The clear advantage of the discrete display, in contrast to the typical time-series aggregation using scaled scores such as Goldstein's (1992) is that we can see that at least some limited cooperation was occurring even during a period that was primarily conflictual. In contrast, in scaled data the evidence of the cooperative behavior is completely swamped by the high level of conflictual behavior.

Application 2: Rule Enactment Moving Averages

In order to track the rule-based patterns over a long period of time, the indicators of rule enactment were downloaded from the EP Tool Web site using the ''Text'' option, and then read into MS-Excel. The TFT, olive branch, and meta-patterns were examined by graphing moving averages of the frequency with which the patterns occur.

Because there are 4485 points in the complete data set (April 15, 1979 to December 31, 2003 in 2-day intervals), it was necessary to construct some means of summarizing the results. The figures below give 32-day moving totals of the number of times that a pattern was matched: this measure has the value of 16 if the pattern matched in every one of the 2-day periods in the 32-day interval. The values for Israel and Palestine are ''mirrored'' across the *X*-axis, with the counts for Israel above the axis and Palestine below.

As we anticipated, there is a very large discontinuity in all of the graphs following 1999, where event counts jump significantly. This is likely due to two factors, one involving the situation and one involving the data. The situational discontinuity was the outbreak of the second Palestinian *intifada* in September 2000. The level of violence during this period was substantially greater than that experienced during the first *intifada* in 1988–1991, and consequently the number of reports of violence is objectively higher. However, we also have a change in data sources at this point, with Reuters prior to October 1999 and Agence France Presse (AFP) following that period. As discussed in Schrodt, Gerner, and Simpson (2001), AFP generally has a much higher density of coverage of the Israel–Palestine conflict than Reuters has in the periods where we can examine the coverage of both sources. Consequently some of the increased intensity of coverage is, in all likelihood, due to the change in data sources.

Whatever the cause, the net effect of these two changes is that the data during the period 2000–2003 generally overwhelm our indicator threshold values, which either spike to their maximum values for the entire period or go to zero. Because we frequently see this occurring for measures of *both* conflict and cooperation, it seems more likely to be an artifact of the increased coverage of AFP. The solution to this problem would be to use higher thresholds for the AFP data; we intend to experiment with this adjustment at a later date.

Tit for Tat Analysis:
Figures 4a and 4b show the 32-day moving totals for incidences of conflictual and cooperative TFT, which were compiled separately (i.e., conflictual TFT refers to a period of material conflict by one side followed by a period of material conflict by the other); a color version of this can be accessed at http://nkss.org/fpa/figure.4.htm. Several characteristics are evident in these displays.

First, the behaviors are generally, but not totally, symmetric—generally when one side is engaging in TFT, whether cooperative or conflictual, the other side is doing so as well. There is no reason that this must be the case, but the fact that we observe it suggests that the two antagonists are implementing a classical TFT solution to the prisoners' dilemma game. Unsurprisingly, give our qualitative understanding of the conflict, they are far more likely to be playing DD than CC.

Second, most of spikes in the conflictual TFT correspond to periods of substantial violence such as the first and second *intifadas* and Israel's 1982 invasion of Lebanon, which was initially directed against the ''state within a state'' controlled by Palestine Liberation Organization forces, providing evidence of the face validity of these representations. The outbreak and decline of the first *intifada* from December 1987 to August 1990 shows the same exponential-decay shape that is seen in Goldstein-scaled data for the period (Schrodt and Gerner 1994). Similarly, the negotiations following the Oslo agreement in September 1992 and prior to the outbreak of the second *intifada* in September 2000 are evident.

The surprising aspect of these two graphs is the juxtaposition of TFT conflict *and* cooperation during the post-Oslo period. This is not an error and is an illustration of the utility of objective DSR analysis over vaguely remembered narratives: one tends to forget that while the Oslo period saw nowhere near the levels of violence seen in the second *intifada,* there were periods of substantial conflict, such as the four suicide bombings in Tel Aviv and Jerusalem and subsequent Israeli reactions to these in the spring of 1996, shortly after Israel's military withdrawal from Palestinian urban areas. Conversely, negotiations continued at both the official and unofficial levels (e.g., the Geneva Accords between Israeli and Palestinian citizen elites) during the second *intifada.* DSR analysis can thus be used to augment the qualitative record.

Olive Branch Rule:
The second set of rules we looked at were the ''olive-branch''—instances where one side engaged in cooperation despite having experienced conflict from the

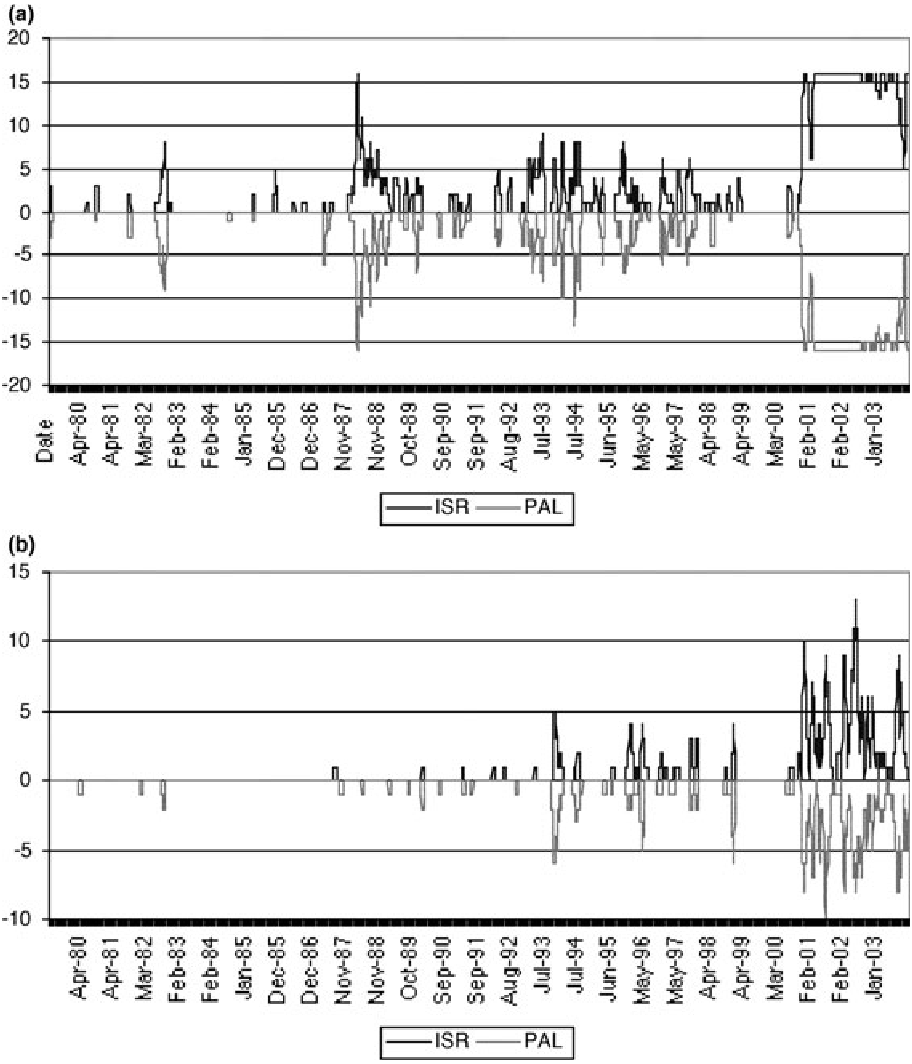

Fig 4. (a) Tit-for-Tat Conflict. (b) Tit-for-Tat Cooperation.

other side. These instances are shown in a 32-day moving total in Figure 5; a color version of this can be accessed at http://nkss.org/fpa/figure.5.htm.

The olive-branch pattern turns out to be far better than the cooperative TFT pattern at delineating the Oslo period. Like cooperative TFT, one also sees olive-branches occurring during the second *intifada*, but we believe that this is consistent with the narrative record. It is also interesting to note that one sees a number of olive-branch instances following the outbreak of the first *intifada*, and continuing in a sporadic pattern until the Oslo agreement. This would appear to be consistent with changes in Israeli policy as leaders experimented with a variety different levels of response to the *intifada*, and to international pressure for a resolution of the dispute following the first Iraq war in 1991. The qualitative record indicates that the Israeli response to the first *intifada* was indeed marked by shifts in strategy. As the violent response to the unrest in the territories proved to be ineffective, it became clear to Israeli leaders that a more ‘‘political’’ solution was required (i.e., the offering of olive branches to effect a long-term solution to the conflict) (Morris 2001:587, 589).

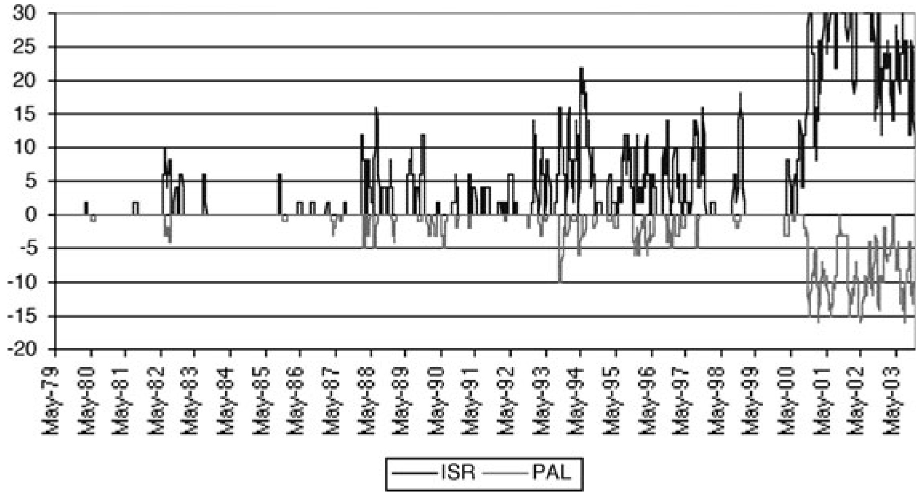

FIG. 5. Olive Branch Pattern.

The olive-branch patterns show substantially less symmetry than was seen in the TFT graphs, even in the post-Oslo period. Some of this may be a calibration issue: events with Israel as an actor are consistently reported more frequently than events with Palestine as an actor. However, this is unlikely to be the only explanation, given the symmetry for the TFT rules. A more likely explanation is that the Palestinians, as the weaker party, are more likely to be the follower than the leader in offering cooperation. This inference is also consistent with the pattern seen in the cooperative TFT graph prior to Oslo: there are a number of instances when the Palestinians engaged in cooperative TFT—that is, the Palestinians cooperated following cooperative behavior by Israel—but this was rarely reciprocated by the Israelis, as seen by the absence of spikes above the *X*-axis. This might have led the Palestinians to become less inclined to initiate olive-branches, since their experience was that unilateral cooperation would not be reciprocated. A final possible explanation may simply be the fact that Israel has a much stronger and cohesive state structure and is therefore better able to implement policy shifts. Prior to the Oslo process, the Palestinians had very little to offer the Israelis in terms of material cooperation.

An interesting example of the olive-branch pattern in the display can be seen in the Web-based Figure 6 (http://nkss.org/fpa/figure.6.htm). We selected this because it was a frame that ''jumped out'' when the display as a whole was being scanned—one of the advantages of a visual DSR display. Suddenly a long series of olive-branch indicators (gold triangles) appear on the Israeli side, with some limited reciprocity on the Palestinian side.

This appeared sufficiently unusual that we went back to the original source texts to see what was going on. As the figure caption indicates, this was the period of U.S.-mediated negotiations at the Wye Plantation conference center which were attempting to get the Oslo process back on track amid a deteriorating security situation. As the negotiations were presented in the press reports, Israel—under U.S. pressure—was offering a number of concessions, while the Palestinian negotiators generally concluded that the U.S. was taking a position that favored Israel's interests and did not consider these offers to be adequate implementation of the earlier Oslo agreements. While it obviously does not provide all of that information, the visual DSR display does vividly signal that something interesting is going on, alerting the researcher to investigate further.

One of the interesting interpretations from this initial analysis is the meaning of the olive branch rule enactment. Remember that olive branch is a pattern wherein conflict by one side is met with cooperation by the other. What we found in our initial analysis is that olive branches were often extended by each side *in the context of simultaneous conflict.* That is, olive branches were usually held out in the midst of a TFT exchange of conflict. How this played out is that one side would engage in conflict, and then the other side would return with both conflict and cooperation. The signal became, ''You have the choice about which of our actions to reciprocate. You can reciprocate the violence, or you can reciprocate the peace. And then we will follow suit.'' There was no logical necessity for the rule to be used in this manner, but it took on that meaning in the context of Israeli–Palestinian relations. It is indeed nearly impossible to find in the qualitative record an instance where an olive branch that received a violent response was followed by another olive branch, which is consistent with Axelrod's (1984:62) hypothesis that successful strategies in Prisoners' Dilemma situations must be ''provokable'' as well as ''nice.''

Application 3: Meta-Patterns

A further set of experiments dealt with looking at the incidence of ''meta-patterns.'' These were implemented as four boxes of different colors at the right-hand edge of the display, and were intended to detect both the level of escalation and de-escalation in the activities, as well as its consistency. The four rules are given at the end of Table 1, with each meta-rule represented by a colored box of red, black, yellow, or purple located in the far right column of the display. If none of the meta-rules apply, the final column is left blank.

In one sense, the red (asymmetric conflict) and purple (mixed conflict and cooperation by both sides) boxes represent *transition states* for Palestinian-Israeli interaction; the black (symmetric conflict) and yellow (symmetric cooperation), *inertial states.* Making sense of the meta-rules has thus far proven more difficult than we anticipated, in part because they fluctuate quickly. Graphs similar to those used for TFT and the olive-branch rules are not particularly informative, so instead we spent some time simply looking through the entire display and trying to determine patterns using that highly sensitive pattern recognition device, the human visual cortex. Using this exploratory approach, two trends in the meta-patterns may be described.

First, to use Wolfram's phrasing, ''purple grows.'' In the parts of display prior to the Oslo Agreement in 1993, signals are usually unambiguous: there is either conflict or the absence of conflict, and the meta-boxes are either black, red, or absent (mutual cooperation unaccompanied by conflict is rare during this period, as we saw in Figures 3 and 4). In the post-Oslo period, in contrast, purple becomes more and more dominant, indicative of mixed conflict and cooperation. This is, in all likelihood, a reflection of a critical change in the situation: the rise of Islamic militant groups which challenge the legitimacy of the Palestinian Authority and the Palestine Liberation Organization as the sole ''voices'' of the Palestinian opposition to Israel. A second factor that may also be contributing to this is the increase in visible international mediation, particularly by the United States and Europe, which, until recently, strongly encouraged talks between Israel and Palestinian representatives even when there was a high level of violence on the ground.

The second meta-pattern that we have noted is that the majority of the meta-boxes are red: following a period of no cooperation, conflict is initiated by one side or the other, rather than simultaneously. Lest this seem obvious, one should note that this is quite a different pattern than one sees in a conventional war, where the most common pattern would be that the two sides ''meet on the field of battle'' and engage in conflict simultaneously. In the Israel–Palestine conflict, the dominant pattern is instead *asymmetric* conflict incidents, typically in the form of brief Israeli military raids and even shorter small-scale Palestinian attacks such as violent demonstrations, attacks on Israeli settlements, and (following 1996, when the tactic was introduced) suicide bombing. While generally these occur in a TFT fashion, there is a significant time lag between the stimulus and response and this therefore triggers a red meta-rule. The qualitative record confirms that it is often the case that periods of TFT violence are clearly initiated by either side in an asymmetrical fashion that appears unprovoked in the time frames examined. For example, even though the violence of the first *intifada* was winding down in late 1991–early 1992, Israel engaged in unilateral violent action (the assassination of Hamas and Islamic Jihad leaders) that ultimately provoked further violence after a lag: for example the Hamas retaliation to the assassination of Yahya Ayyash did not occur for almost 8 weeks.

This analysis suggests to us that the Israeli–Palestinian conflict is dominated by transition states, first red and then purple. The dialogue of actions between the two sides is never stagnant for long, but is continually evolving.

A couple of other patterns appear to suggest themselves, but we need to do further systematic analysis to determine whether these are actually occurring at a level beyond that expected by chance. First, it appears that in the pre-Oslo period, Israel tends to get the ''last word'' in a period of extended conflict—that is, it is an Israeli action that triggers the last occurrence of a red meta-box. Following Oslo, these ''last words'' shift over to the Palestinians. If this shift is in fact real, it may be another manifestation of the decentralization of Palestinian militant activity following Oslo, and the more intense antagonism of the Islamic militant groups towards Israel compared to the policies of Fatah and the Palestinian Authority.

The other general change between the pre- and post-Oslo pattern—and this involves an overall assessment of the display, not just the meta-rules—is the increase of material cooperation (typically, agreements) by the Palestinians. Prior to Oslo, ''cooperation'' by the Palestinians was simply the absence of conflict; following Oslo we start to see cooperation events, even during periods of conflict. Again, much of this can be explained by the fact of mutual recognition that came with Oslo—prior to Oslo, the two sides had no public arena in which to cooperate. Israel, as the occupying power, could engage in unilateral concessions to the Palestinians (e.g., easing restrictions), but there could be no parallel official Palestinian response. This situation changed following the Oslo agreement.

Application 4: Analyzing Pause and Provocation in Israeli–Palestinian Interaction

To this point, we have relied on only three rudimentary rule-based patterns: TFT, olive branch, and the four meta-patterns. In this section, we want to push the idea of patterns and rules a bit further by looking at more complex interactions.

If we operationalize the ''pause rule'' as on in which one side offers material cooperation behavior accompanied by a relative lack of material conflict for several days, are such pauses used in Palestinian-Israeli signaling? The Web-based Figure 7 (http://nkss.org/fpa/figure.7.htm) illustrates one example from late 1982, following Israel's invasion of Lebanon, an operation directed against the PLO. The filled boxes in the column to the right identify the use of the Israeli pause, a signal that is repeated four times, with 2–3 weeks of interval between. This is apparently a technique to lift the signal higher than the background noise level in the event stream. The Palestinians do begin to reciprocate the syncopated pause (open green squares, with one filled green square—material cooperation—near the end), in what is presumably an attempt to begin and maintain a de-escalatory sequence with the Israelis.

To further explore the issue of pausing—and also to illustrate the flexibility of the display—Figures 8–10 result from a modification of the display that shows only the raw data, crosses and dashes indicating above-threshold cooperation and conflict, and the presence of ''pause'' behavior in a 3-day interval display: this is in the two right-most columns, with a black diamond indicating a Palestinian pause and a red diamond indicating an Israeli pause.

Palestinians' use of the pause, denoted by a red diamond, in the Web-based Figure 8 (http://nkss.org/fpa/figure.8.htm) shows an effective Palestinian use of pauses leading to a period of relative calm between the two sides in the months prior to the outbreak of the second *intifada*. The Israeli response includes offering some material cooperation, a decrease in conflict (delayed by about a week in the second instance), and a reciprocal pause of the same length as the Palestinian pause.

Pauses are not always reciprocated, nor do they always work. For example, the Web-based Figure 9 (http://nkss.org/fpa/figure.9.htm) from the second-half of 1997 and early 1998 (this interval is twice as long as that in previous figures) shows a period when the temporary lull in violence that characterized the early part Oslo process was beginning to break down as Israel became involved in TFT material conflict with Palestinian militant groups opposed to Oslo, while still engaging in considerable material cooperation with the pro-Oslo Palestinian Authority. We see first see a pause by the Israelis, a brief reciprocal pause on the Palestinian side, and then an extended series of pauses by the Israelis. However, when these are not reciprocated, the Israelis begin a long episode of conflict with one additional short pause, also not reciprocated. No additional pauses are found until near the end of 1998.

Do both sides ever pause at the same time? Yes, and the inauguration of matched pauses actually delineated the Oslo period. These matched pauses ratchet down the violence between the two sides as well, though not eliminating it by any means. This can be seen in the Web-based Figure 10 (http://nkss.org/fpa/figure.10.htm).

A second non-traditional rule-based pattern is provocation—the initiation by one side of new hostilities after the other side has not reached their threshold for material conflict for over a week. Provocation is used more often by the Palestinians than the Israelis, though this may partly be a function of the slower response of the Palestinians to earlier Israeli actions. However, there are two interesting phenomena apparent in the data. First, over time the Israelis appear to ''learn'' provocation from the Palestinians, and their use of this rule increases over time after it has been used considerably by the Palestinians. And, second and quite counter-intuitively, provocation often precedes a period of relative calm. That is, the other side may briefly strike back, but then both the victim and the provocateur cease conflict for a time. Perhaps this is a way of testing the resolve of one's adversary, or may mark the end of a TFT: there is an action, a retaliation, and then the situation is temporarily resolved. The Web-based Figure 11 (http://nkss.org/fpa/figure.11.htm) is an example from early 1983, with open red boxes representing provocation.[5] This provocation episode is initiated by the Palestinians, and then is followed about a week later by the Israelis, but does not lead to an escalation, probably in large part because the international community was actively involved to trying to contain the conflict at this point, and, due to the presence of a multi-national peacekeeping force in Lebanon, could be effective in doing so.

[5] An almost identical pattern, is found in the summer of 1990, as shown in the Web-based Figure 12 (http://nkss.org/fpa/figure.12.htm).

There is also an apparent organizational difference in ability to respond to a provocation. Unsurprisingly, it appears that it takes the better part of a week or more for a Palestinian response to an Israeli provocation, and the Palestinians appear less able to respond consistently. An example of this can be seen in the Web-based Figure 13 (http://nkss.org/fpa/figure.13.htm)—note that this covers twice as long a time period as the previous figure—which shows the period when the first *intifada* had been going for about a year. In general we see the same sequential exchange of multiple provocation patterns that were seen in Figures 11 and 12, but the difference is that while the Israelis respond fairly quickly to the Palestinian provocation sequences except at the end of the period (which is characterized by about a month of relative calm, then picks up in the next frame with another set of mutual provocation squares), there are two instances where the Palestinians do not respond, and more generally their responses are slower. There appears to be a clear difference in organizational ability for retaliation between the Israelis and Palestinians.

This exercise of postulating two additional rule-based patterns, pause and provocation, has allowed us to ''see'' in an even more detailed fashion than before the interaction that the Palestinians and the Israelis are co-creating. We find learning, we find forbearance, we find differences in organizational capacity. As we move forward with this project, we hope to extend our line of sight even further. Though this initial exploration involved primarily thick description of Palestinian-Israeli interaction to demonstrate face validity, in subsequent efforts we will be able to generate hypotheses and engage in efforts at falsification.

Future Directions

Our future work on this project includes the following components:

Rule Substitution Over Time and Complex Rules

As we have observed throughout this article, we would expect to see changes in rules over time as regimes and personalities change, and as there is some co-evolution of strategies by the antagonists. The facilities in EP Tool also allow the specification of far more complex rules than we have developed here. Game theory suggests a number of other strategies—for example, brinksmanship, escalation, and ultimatum—that could be explored. We would initially look at these with respect to fairly simple consequents such as the presence of conflict versus cooperation, but we should also be able to scale up to more complex consequents such as escalation and de-escalation sequences, for the KEDS verb dictionary allows for quite nuanced categorizations of behavior, which we have not fully exploited in this initial exploration.

Incorporation of Substate Actors

The KEDS project has recently developed a set of coding rules that allow substate actors to be coded in considerable detail and with much greater consistency that was found in earlier event data sets such as WEIS (Gerner, Yilmaz, and Schrodt 2006). As noted throughout the analysis in this paper, one of the major problems we have had in reconciling the patterns we find in the event data with the qualitative record has been the fact that substate actors, particularly on the Palestinian side, have been pursuing multiple, and oftentimes competing, agendas. The new CAMEO data will allow us not only to distinguish the PLO and Palestinian Authority from various Islamist groups such as Hamas, but also make distinctions between events occurring in the West Bank and Gaza. The role of substate actors is less critical on the Israeli side, but we are still likely to find some instances where the patterns make more sense when we distinguish between Israeli government and opposition parties or other indigenous groups—which the new coding system can do—as well as breaking out acts of violence committed by Israeli settlers rather than the military. Indeed, a potential strength of the DSR approach would be the ability to explicitly model these multiple agendas. There is no necessity to examine only dyads with DSR models—the behavior of dyads up to N-ads can be analyzed.

Evaluation of Actual Rules Against Random Data and Random Rules Against Actual Data

What is the probability that we are simply finding these patterns by chance? These assessments are comparable to the probabilities of type I and type II error in statistical analysis. Specifically, we want to assess the probability that rules we have specified based on the qualitative and theoretical literature will be found in a sequence of events generated randomly. This assessment can be done on various sets random data sharing increasing levels of structure with the true data, for example by using Monte Carlo methods to generate data sets with the same marginal distribution with respect to the number of events by dyad but with a uniform distribution across event types; then adding the additional restriction that the marginal distribution of event types correspond to the actual data; then adding the additional restriction that the marginal distribution of complementary event pairs correspond to the actual data, and so forth.

Conversely, we would also like to assess the probability that randomly generated rules will be found in the actual data. In other words, to what extent are there ‘‘rules’’ in any event data set? This is a somewhat more difficult problem since it requires developing the concept of a ‘‘random rule’’ but by modifying Wolfram’s methods for specifying a space of discrete rules, it should be possible to do this systematically. These steps forward will develop the stochastic foundation necessary for hypothesis testing and falsification.

Conditional Probability Assessment

Letting X be the antecedent and Y the consequent, we are interested in looking at

Predictive rules: $P(Y|X) >> P(Y)$
Null rules: $P(Y|X) = P(Y)$
Incorrect rules: $P(Y|X) << P(Y)$
Dormant rules: $P(X) \rightarrow 0$
Comparison of rules: $P(Y^*|X)$? $P(Y|X)$

(This approach follows, but considerably extends, the analysis in Mintz and Schrodt 1988). We are also interested in identifying the time periods when the antecedents of rules are encountered with a high frequency ($P(X)$) as distinct from situations where $P(Y|X)$ is high—that is, distinguishing between whether a rule might be invoked because the requisite antecedent conditions are present from situations where the rule was ‘‘correct’’—both the antecedent and consequent were found. The frequency and conditional probabilities are two different measures and it will be interesting to explore relationships between the two. We are also interested in rules that are encountered with a low frequency: for example we would not be surprised to find that overall behavior involves a combination of high-frequency ‘‘standard operating procedures’’ that account for most behavior and low-frequency ‘‘crisis behavior’’ that also occurs predictably but only in exceptional circumstances.

In the process of discussing this possibility, however, we have also encountered another issue: when is a rule ‘‘interesting?’’ That is, there are undoubtedly a number of trivial rules that have high predictive conditional probabilities, but they predict behaviors that are routine either in the sense that they occur frequently in the data set, or they are uninteresting for substantive reasons. ''Interesting'' rules, in contrast, probably involve a combination of novelty—the rule predicts a pattern that has not occurred frequently earlier in the data set—and substantive utility—the rule predicts events with a clear theoretically relevant interpretation, for example the escalation or de-escalation of the conflict, rather than something pattern that is rare but has no obvious meaning.

An obvious starting point for a conditional probability assessment is regime change. We have already begun an analysis of rule enactment by the various Israeli governments in the KEDS dataset, and are able to confirm differences in tactics and approaches used by each prime minister (Schrodt, Hudson, and Shanko, unpublished data).

Conclusion

Event data have been employed in the analysis of international behavior for over four decades, but arguably we are still trying to learn how to use them effectively. This type of data—a nominal time series—is rarely encountered in other fields such as economics and industrial process control that make extensive use of statistical methods, and consequently there are relatively few places from which we can borrow techniques. Instead we must invent our own.

This paper has been an initial foray into the realm of using DSR models as a tool for event analysis. The work presented here has been primarily an exploration of the potential of this approach, starting with thick description: since no one had looked for patterns in this fashion before, we first needed to demonstrate that we could find them, and that the patterns had some plausible correspondence to our underlying qualitative understanding of the situation we were analyzing. A further comparison of the visualized patterns produced by DSR modeling and the qualitative historical record indicates a fairly robust level of face validity for the overall approach (Schrodt, Hudson, and Shanko, unpublished data). One utility of this approach is that we can go almost directly from theoretical specifications of strategic moves to determining instances of these in events data of real international interaction, rather than doing so only in laboratory or simulation situations.

At first glance, the displays may seem complex, but we would suggest this approach is actually much less complex than mainstream statistical–mathematical techniques used in IRFP. Almost everything in our model is ''out front'' in the displays we present here, with no hidden assumptions (other than the mechanics of the program that generates the display). In contrast, the estimation of a logit equation (or even a simple OLS) is hugely more complex in its assumptions, but because they are hidden from view we do not think about this. In a sense, our mainstream techniques merely ''pass'' for being parsimonious, and that in itself may present a problem.

We are encouraged by our initial results in thick description and face validity assessment. One of our concerns when we embarked on the analysis was whether we would posit plausible patterns and find nothing in the data. Our experience has, instead, been the opposite—the problem is not that we are finding too little, but we are still finding too much. When one combines the remarkably rich set of patterns that can be constructed using the quite simple aggregation methods available in the pattern-specification language with the ability to rapidly construct colorful, Web-based displays at a very fine time interval, the possibilities for DSR analysis increase substantially. With a few exceptions, we are finding very credible ''patterns in the patterns''—these do not occur at random, but instead their rise and fall generally tracks changes in the political situation which we know about from qualitative narratives. Furthermore, we are able to flesh out the qualitative historical record, remembering things we might otherwise forget, such as conflict during the Oslo period and cooperation during the *intifadas*, by using DSR models.

Computational Irreducibility and Social Science Explanation

DSR modeling raises some interesting epistemological issues, however; issues raised by Wolfram himself. If pattern recognition is the basis of human understanding of human behavior, then while one can specify rules that govern human behavior, it will be impossible to know for a surety in advance all of the consequences produced thereby. *Many* consequences can be known, but never all: one can explain, in the sense of identifying *ex post facto* the rules that generated a set of behavior, but not necessarily predict those in advance. As a result, there is, as Wolfram puts it, a ''computational irreducibility'' about rule-governed human behavior. This means that there is a limit to prediction in any theoretical science of social phenomena. In dealing with complex phenomena such as social behavior, a theorist will have to readjust his sights: specification of the rules, and an understanding of less than all of the consequences thereof, will now be his aim. Wolfram puts it this way:

> In traditional science it has usually been assumed that if one can succeed in finding definite underlying rules for a system then this means ultimately that there will always be a fairly easy way to predict how the system will behave.... But now computational irreducibility leads to a much more fundamental problem with prediction. For it implies that even if in principle one has all the information one needs to work out how some particular system will behave, it can still take an irreducible amount of computational work actually to do this.... And this, I believe, is the fundamental reason that traditional theoretical science has never managed to get far in studying most types of systems whose behavior is not ultimately quite simple. [...]. And indeed I suspect the only reason that their failure has not been more obvious in the past is that theoretical science has typically tended to define its domain specifically in order to avoid phenomena that do not happen to be simple enough to be computationally reducible. (Wolfram 2002:737–742)

Our experiments with DSR modeling, then, have led us to modify our explanatory aims as social scientists, which new aims then modify our definition of causality when attempting to understand human behavior. The act of imputing causality *is the act of identifying rule-based patterns in the phenomena we study*, with the caveat that the complete consequences of the rules specified are probably not going to be knowable in advance. Wolfram states, ''whenever computational irreducibility exists in a system it means that in effect there can be no way to predict how the system will behave except by going through almost as many steps of computation as the evolution of the system itself'' (Wolfram 2002:739). In general, then, there are no valid shortcuts to take, for we are not operating in a context of computational reducibility (generally speaking) in the social sciences.

We do not view this modification of the aims of social science to be unfortunate in any way: on the contrary, we believe it to be a more realistic, though unconventional, approach to understanding social phenomena. Such a readjustment of our sights opens a whole new methodological vista, and this may be a very healthy turn of events. If social science can develop new methodologies that are capable of preserving the agential basis of social interaction, capable of analyzing the rules behind such purposive behavior, capable of tracking multiple agents as they enact rules through behavior directed at one another, and capable of capturing the evolution of such interaction over time, it will possess the capabilities necessary to move past the current stage of relative methodological anomie. We believe that DSR modeling may reasonably be expected to be part of that emerging tool set.

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