Reciprocity and Shared Knowledge Structures in the Prisoner's Dilemma Game

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A prominent solution to achieving cooperation in prisoner's dilemma situations is repeated interaction between players. Although indefinitely repeated play solves the mutual gains problem, it also creates an unsolved coordination problem because an infinite number of strategies are possible in equilibrium. This article explores whether a "shared grammar of strategies," formalized by a knowledge-induced equilibrium, resolves the coordination problem by prescribing a unique behavioral rule. Applied to the set of strategies submitted to Axelrod's prisoner's dilemma tournament, tit for tat emerges as that unique coordinating strategy.

The prisoner's dilemma game, with its simple representation of the tension between individual self-interest and collective cooperation, is the basis for countless applications, ranging from superpower conflict to the management of common pool resources (e.g., Rapoport and Chammah 1965; Hardin 1982; Brams 1985; Taylor 1987; Ostrom 1990). In the standard prisoner's dilemma game, each of two players has a choice whether to cooperate or defect. Using Axelrod's (1984) payoff values, if both players cooperate, they each get a reward payoff of 3; if both defect, each receives the punishment payoff of 1; if one player defects and one player cooperates, then the defector gets the temptation payoff of 5 and the cooperator gets the sucker payoff of 0. If the game is played once, defection is the dominant strategy, and players fail to achieve the gains from mutual cooperation. However, if the game is repeated indefinitely (with discounting or with a constant probability of another round), then the mutual gains of cooperation can be sustained by the use of *conditionally cooperative strategies* (also called reciprocity, reciprocal altruism, or social exchange), in which players' cooperation hinges on their actions being reciprocated by others (Axelrod 1984; Taylor 1987; Cosmides and Tooby 1989). Anthropologists and evolutionary psychologists, who note that all societies have social norms based on conditional cooperation, reinforce the theoretical attention to conditional cooperation (Cosmides and Tooby 1992; Sober and Wilson 1998).

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But although repetition solves the mutual gains problem, it creates an unsolved coordination problem in that an infinite number of strategies, defined as complete instructions for all contingencies, are possible in equilibrium (Fudenberg and Maskin 1986; Boyd and Richerson 1992; Nowak and May 1992). Unless strategies are differentiated in some way, there is no theoretical prescription as to how and where players coordinate their actions. Furthermore, the practical achievement of coordination is even more forbidding because of the challenges of communication, monitoring, and noise. Although most attention focuses on the subset of conditionally cooperative strategies, conditional cooperation remains an incomplete solution to social exchange because a puzzle remains as to *which* behavioral rule from the enormously large set of feasible strategies emerges as the coordinated social norm. But the very idea of a norm is to coordinate expectations of behavior on a single rule of conduct, thus economizing on the high costs of social monitoring and achieving the mutual gains of social coordination. The existence of a norm maintains and creates an equilibrium among players' actions and can serve an important function in maintaining a cooperative equilibrium in situations of noise. Furthermore, coordination best succeeds with a single behavioral rule because the effectiveness of any conditional strategy is based on its response to deviations from the equilibrium, which depends on a shared conjecture about what punishments are used to enforce cooperation (Morrow 1994). When understandings of punishments are shared, then deviations to a cooperative equilibrium are less likely and, when they do mistakenly occur, players are more likely to be able to differentiate targeted punishment from a general collapse of coordination.

The reciprocity strategy that has received the most attention is tit for tat, which begins by cooperating and then chooses whatever the other player chose on the previous round. However, the attention to tit for tat can be seen as puzzling. Tit for tat is not the panacea to the indefinitely repeated prisoner's dilemma (IPD). It is only one of an extremely large set of feasible strategies that includes both strategies that are and are not the first to defect (Binmore 1994). Although tit for tat had the highest score in Axelrod's round-robin tournament, it never does better than its opponent, and other strategies have been found that outperform tit for tat (Axelrod 1987; Nowak and Sigmund 1993). It is also based on punishment threats that are not credible (i.e., it is not subgame perfect). Furthermore, tit for tat is not an evolutionarily stable strategy (Axelrod and Dion 1988).

Why so much attention to tit for tat? Binmore (1994) suspects that tit for tat's idea of simple reciprocity resonates with our societal beliefs, so when tit for tat performs well we seize on the evidence. The approach taken here is consistent with Binmore's conjecture but combines two theoretical insights. First, I consider the possibility of a "shared grammar of social contracts" applied to strategies as behavioral rules (e.g., Crawford and Ostrom 1995; Romney et al. 1996). For example, Cosmides and Tooby (1992) presented evidence for shared cognitive structures in two other aspects of social exchange: recognition skills and the detection of cheating. Sociologists also emphasize the extent to which commonly shared norms are internalized in a "privileged position in the individual's cognitive structure" (Hechter, Opp, and Wippler 1990, 2). Here I consider the possibility that strategies, as behavioral rules for social exchange, are subject to a shared grammar in that they are understood and organized with shared representations. Second, I use the concept of a "knowledge-induced equilibrium," which is a coordination solution among a set of categories organized with a shared mental model (Richards 2001). Examining the set of strategies submitted to Axelrod's (1980) original prisoner's dilemma tournament, I find that tit for tat emerges as the unique prominent coordination solution.

KNOWLEDGE STRUCTURES OF STRATEGIES

Strategies are typically modeled as an unstructured continuous set without attention to the relationships and meanings of the behavioral rules prescribed by each strategy. For example, formal approaches focus on the folk theorem of repeated game theory, which states that any payoff in the convex hull of players' minimax payoffs can be achieved by some strategy in equilibrium. In the folk theorem, strategies are considered as a collection of continuous undefined points in a region of the payoff space. Similarly, most evolutionary approaches pay little attention to the meaning of or relationship between strategies and conceptualize the behavioral rules over a generic abstract continuous space (e.g., Lindgren and Nordahl 1994). Strategies are specified as n-bit strings, and any permutation of the 2^n strategies are allowed—many of which are admittedly not even interpretable in a higher level language (Lindgren 1991).

In contrast, the emphasis here is on the cognitive organization of strategies as meaningful discrete categories of behavioral rules. A *knowledge structure* is a representation of the cognitive organization of a set of objects and is a structure in that it mediates between individuals and their world—much as social constraints or political institutions are also structures (e.g., Converse 1964; Shepsle 1979). Knowledge structures encompass a variety of objects, including the mental landscape of political parties, analogies between events (e.g., Khong 1992), cause-and-effect models, and, most relevant here, actions or strategies. As in Richards (2001), the cognitive organization of a set of objects is modeled simplistically with two components: a set of objects and the similarity relations between the objects. In this article, the objects of the knowledge structure are strategies for playing the indefinitely repeated prisoner's dilemma game. Specifically, a knowledge structure is depicted as a graph, where each node is a strategy, and a link between two strategies indicates that they are closely related in a player's mental organization. Strategies that are not adjacent are more cognitively distinct in a player's mental organization. Similarity between two objects is captured by the extent to which the pair shares features in common (Tversky 1977). In the case of strategies for the IPD, the feature set includes attributes such as how a strategy begins, whether it uses randomization, whether it engages in learning and if so by what rule, and so on.

To illustrate how strategies can be organized into a knowledge structure based on their relative features, consider the case of the Cuban missile crisis and the deliberations by the executive committee of the National Security Council (ExComm). Over several days, the ExComm discussed at least six alternatives with which to respond to the placement of offensive missiles in Cuba. Each alternative was a strategy in that it consisted of a sequence of likely scenarios and counterresponses[1] (Blight and Welch

1989, 60; Allyn, Blight, and Welch 1992, 117, 342). For example, the alternative of a surgical air strike included not only plans for removing the missiles but also for responding to Khrushchev's likely threats to either Berlin or Florida (Allyn, Blight, and Welch 1992). Similarly, the blockade—specifically the challenge to a Soviet vessel—was understood as only a "first step" in a sequence of moves (Blight and Welch 1989, 60; Allison and Zelikow 1999, 120). Kennedy and his advisors discussed each strategy's features or attributes in detail, focusing on features such as (1) Does the strategy satisfy domestic expectations for action? (2) Does the strategy comply with international law or ethics? (3) Does the strategy entail an acceptable risk of war? (4) Does the strategy demonstrate U.S. resolve and credibility? and (5) Is the strategy likely to remove the missiles? (Blight and Welch 1989; Blight 1990; Allyn, Blight, and Welch 1992; Allison and Zelikow 1999). Through these discussions, members reached a shared understanding of the strategies' features. Each strategy was discussed and positioned relative to other strategies in terms of these features. For example, the strategy "do nothing" was understood as failing to satisfy domestic expectations, complying with international law, entailing little risk of war, failing to demonstrate U.S. resolve, and unlikely to remove the missiles. The strategy of a ground invasion was understood by the ExComm as satisfying domestic expectations, entailing some international law issues, being extremely risky as the first direct confrontation between U.S. and Soviet troops, demonstrating U.S. resolve, and likely to remove the missiles. The alternative of a naval blockade (or "quarantine") consisted of two strategies: one that demanded a commitment to remove the missiles and one that relied on negotiations (Blight and Welch 1989, 65-67; Allyn, Blight, and Welch 1992, 99-100; Allison and Zelikow 1999). Both alternatives were seen as satisfying domestic expectations, skirting issues of international law, demonstrating U.S. resolve, and reducing the risk of war through a "turning the screw" approach rather than initiating immediate military conflict. The "ultimatum" version carried a higher risk of conflict, but the negotiation version was viewed as less likely to remove the missiles.

Figure 1 shows a hypothetical knowledge structure of the nine alternatives (based on the similarity relations using the five features listed above). Each strategy is a node, and an edge between a strategy pair indicates that the pair shares a number of attributes, the extent of similarity shown by the width of the edge. Strategies such as "do nothing," "diplomacy through the UN," and "secret approach to Castro" are very similar strategies in terms of their features. The strategies of "ground invasion," "surgical air strike," and "massive air strike" are also strongly correlated in terms of their features. Strategies such as "do nothing" and "ground invasion" are very different based on their overlap of the five features. Figure 1 illustrates how strategies can be conceptualized and organized with the structure of a mental model. However, in this case, the strategies are not those of a pure coordination game: although there was a desire for members to concur, ultimately the final decision fell to President Kennedy. Yet, the example does suggest how strategies, as prescriptions for actions, are also understood as objects in a knowledge structure.

However, sharing an understanding of the strategies' features is distinct from sharing opinions as to the best strategy choice. For example, a shared understanding of film genres, such as that suspense thrillers are very different from romantic comedies and

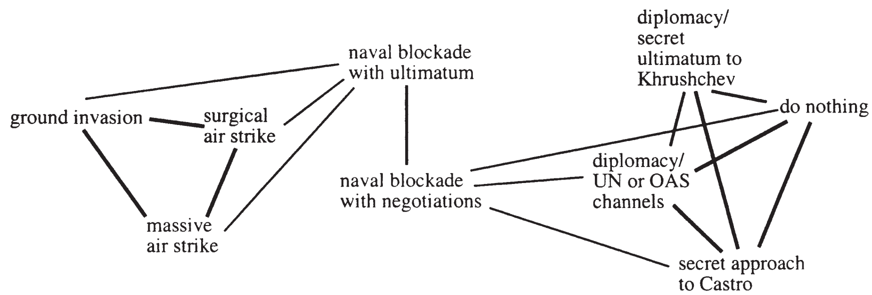

Figure 1: Strategies in the Cuban Missile Crisis
NOTE: OAS = Organization of American States; UN = United Nations.

similar to mystery films, does not imply that two people agree on their most preferred type of film. Indeed, members of the ExComm continued to hold very different opinions of the best strategy. There were clear differences in decision-making style, strong differences in opinions, and active lobbying among the members (Blight and Welch 1989, 49-51, 73, 89; Allyn, Blight, and Welch 1992, 122, 341-43). President Kennedy initially leaned toward the air strike option. Robert McNamara discounted the military significance of the deployment and focused on strategies that solved what he saw as a "political problem." McGeorge Bundy began by advocating a "wait-and-see" strategy but then switched to the air strike option. Adlai Stevenson proposed appealing to the United Nations or the Organization of American States (OAS) and working through secret bargaining channels using the Jupiter missiles in Turkey and Italy as bargaining chips. Maxwell Taylor, Chairman of the Joint Chiefs of Staff, had doubts about the ground invasion option but was only comfortable with the air strike option if it also could be followed with a ground invasion if necessary (Allyn, Blight, and Welch 1992, 97). As McNamara pointed out at the Moscow Conference on the Cuban Missile Crisis held in 1989, "there was a great difference of opinion among the Americans as to what action should be taken" (Allyn, Blight, and Welch 1992, 94).[2] Yet, these disagreements do not preclude the possibility of a shared understanding of the basic relationships between the strategy options.

THE ORGANIZATION OF STRATEGIES IN THE ITERATED PRISONER'S DILEMMA

To examine the structure of strategies in the iterated prisoner's dilemma game, one must start with a finite set of strategies that have substantive meaning. The set of strategies that were submitted to Axelrod's (1980) prisoner's dilemma computer tournament provides an ideal independent sample of strategies. The strategies were submitted by experts in game theory from a variety of disciplines including psychology, political science, economics, sociology, and mathematics and incorporate many important concepts in conditional cooperation, including an assortment of punishment strategies; monitoring and testing of the opponent's behavior; and the use of probability, forgiveness, and exploitation. In addition, the strategies are precisely specified in textual descriptions and computer code.[3] The strategies from the first tournament rather than the second tournament were chosen because the strategies submitted to the second tournament are likely to be biased toward variations on tit for tat given that tit for tat won the first tournament. The results of the first tournament, however, were described as a "surprise" (Axelrod 1984). The first tournament provides 14 strategies (including "random" but excluding "anonymous" because it was unidentifiable in the computer code). In addition, the two unconditional strategies AllC (always cooperate) and AllD (always defect) are included in the set of strategies for comparison, although they do not affect the results.

To analyze the theoretical similarity between the strategies, they must be represented in a universal form that allows for a direct comparison of their features. Following the approach of genetic algorithms, any strategy that can be written in a programming language can be rewritten as bit-strings of a classifier system (Holland 1992). In this technique, a set of instructions, such as a strategy, is translated to a coding system based on a string of 0s and 1s. Each string represents the instruction code for one strategy, and a string is made up of *blocks*, or data positions in the string, for each relevant feature of the strategy.[4] For example, in the coding described in the appendix, the first block contains information as to whether a strategy begins with cooperation (coded as a 1 in the first string position) or defection (coded as a 0 in the first string position). The second block records whether there is a special string of cooperations at the start of the game, and the third block records the length of the cooperative start sequence if one exists. If a particular feature is not applicable or irrelevant for a strategy, then that feature position is coded with a #. For example, the strategy Tullock is represented as [00 1 10 0 10 0 0 # 110 # 0 #], which describes the rule as starts with cooperation, adds extra cooperations at the beginning of the game, the number of these extra cooperations is 10, uses only the other player's choices to determine its own play, uses information from the previous 10 rounds of play, does not keep track of the round of play, is not unforgiving, does not have a simple response to one defection by the other player, instead the response rule is 10% less than the other player cooperated on the preceding 10 moves (coded as 110), and does not check the other player's strategy. The number of necessary blocks to describe a strategy depends on the diversity in the set of strategies. A block is included if there is variation in a feature across at least two strategies. The appendix describes the blocks and the description and coding for each strategy.[5]

The similarity between pairs of strategies is described with an association measure of the extent of agreement between pairs of the sequence codes. The simple matching coefficient, S_{ij}, was used, which measures the number of block matches expressed as a proportion of the total number of blocks (Sneath and Sokal 1973). This measure counts matching blocks rather than matching bits (otherwise irrelevant labeling effects between 00, 01, and 11 are introduced), includes both the presence and absence of features, and imposes no ad hoc weighting on features. One potential drawback is that it ignores possible correlation between feature blocks that describe conditional rule statements. Therefore, an adjusted matching coefficient, defined as the number of block matches expressed as a proportion of the total number of *logically possible* matching blocks, was also considered. Although the analysis was conducted using both measures, the results are presented for the simple matching coefficient because the results are nearly identical for the two measures.

Table 1 shows the association measures between strategy pairs. For example, the strategies tit for tat and Joss are most similar, with an association measure of .92. Stein and Rapoport and AllD make up one of the most dissimilar pairs, with an association measure of .08. To represent this information as a graph, an edge is included between each pair of strategies that is significantly similar (Kruskal and Wish 1978). When constructing this graph, additional information can be gleaned by analyzing the pairwise association measures using multidimensional scaling. This provides a guide to the relative spatial location of each strategy node. Figure 2 shows each strategy as a node, placed in a two-dimensional space using multidimensional scaling, and edges between pairs of strategies that are similar. However, note that it is the association measures and the presence or absence of edges between strategy pairs, not the spatial location of strategies, that are relevant for the analysis that follows.

TIT FOR TAT AS A KNOWLEDGE-INDUCED EQUILIBRIUM

The claim of a knowledge structure approach is that choices have meaning relative to one another and that this cognitive organization potentially provides clues as to which choice among many equilibrium choices is a salient coordination solution (e.g., Schelling 1960). I use an equilibrium concept adapted from Richards (2001), who showed how a shared knowledge structure can induce a unique maximum likelihood solution in coordination problems called a knowledge-induced equilibrium. A knowledge-induced equilibrium is a stable outcome reached under players' mutual understandings of an empirical context (Richards, McKay, and Richards forthcoming).

The puzzle in the IPD game is which strategy, among an infinite theoretical set of conditionally cooperative strategies, is chosen as the norm for reciprocity. The knowledge-induced equilibrium of a knowledge structure is the strategy that minimizes the sum of the "distance" between that strategy and the remaining strategies in the choice set (Richards 2001).[6] However, distance in a graph representation based on actual similarity data can be interpreted in at least two ways, and the choice of this definition may influence which strategy emerges as the maximum likelihood winner. Therefore, I consider two criteria. The first criterion includes all pairs of strategies in which an edge between a strategy pair is weighted by its distance, $1 - S_{ij}$, and the coordination solution is the strategy that minimizes the sum of the distances over all other strategies. The second criterion includes only edges between pairs of strategies that are significantly similar; in this case, the coordination solution is the strategy that minimizes the sum of the step path lengths from that strategy to all other connected strategies.

Regardless of the association measure or the criteria for minimizing distance, tit for tat emerges as the unique knowledge-induced equilibrium of the set of strategies examined. Note that Axelrod's (1980) original strategy set included both "exploitative" strategies (strategies that initiate defections) and nonexploitative strategies. If a strategy does not initiate unprovoked defections, then it is collectively stable (Taylor 1987), meaning that a player cannot unilaterally switch to another strategy and receive

TABLE 1

Association Measures between Strategy Pairs

	AllC	*AllD*	*Davis*	*Downing*	*Field*	*Friedmn*	*Graaskamp*	*Grofman*	*Joss*	*Nydegger*	*Random*	*Shubik*	*S and R*	*T and C*	*TFT*
AllD	.83[a]														
Davis	.50	.33													
Downing	.58	.58	.42												
Feld	.50	.42	.50	.67[a]											
Friedman	.67[a]	.50	.83[a]	.58	.67[a]										
Graaskamp	.42	.25	.42	.33	.58	.58									
Grofman	.58	.50	.50	.67[a]	.58	.67[a]	.42								
Joss	.58	.50	.58	.75[a]	.83[a]	.75[a]	.50	.67[a]							
Nydegger	.42	.33	.50	.42	.33	.42	.25	.67[a]	.42						
Random	.83[a]	.83[a]	.33	.67[a]	.42	.50	.25	.50	.50	.33					
Shubik	.58	.50	.58	.58	.67[a]	.75[a]	.67[a]	.67[a]	.75[a]	.50	.50				
S and R	.25	.08	.42	.25	.50	.33	.67[a]	.17	.42	.25	.08	.42			
T and C	.33	.25	.33	.33	.58	.50	.83[a]	.42	.50	.25	.25	.75[a]	.58		
TFT	.67[a]	.50	.67[a]	.75[a]	.83[a]	.83[a]	.58	.67[a]	.92[a]	.42	.50	.75[a]	.50	.50	
Tullock	.50	.42	.50	.58	.50	.42	.25	.50	.58	.58	.42	.50	.42	.25	.58

NOTE: Expected association by chance = .28, mean association = .51. See the appendix for definitions of strategies.

a. More than one standard deviation above mean association.

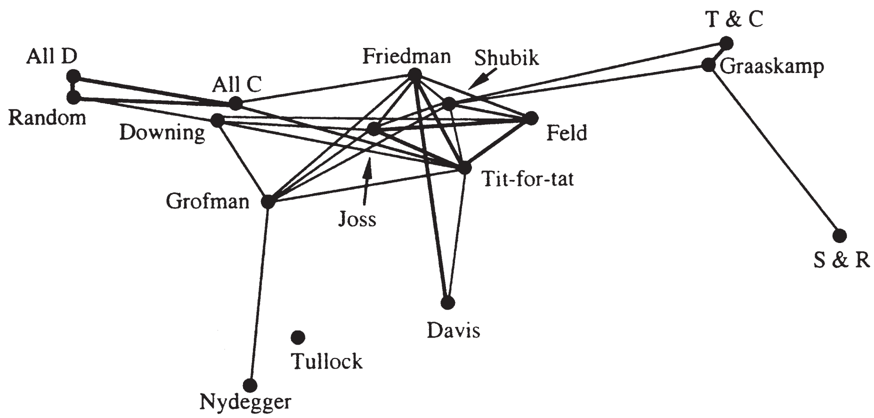

Figure 2: Organization of Indefinitely Repeated Prisoner's Dilemma Strategies Based on Classifier Coding

NOTE: The thick line shows pairwise measures of association two standard deviations above the sample mean; the thin line shows measures one standard deviation above the sample mean. Placement of strategies form multidimensional scaling with slight spreading of central cluster to show edge links.

a greater overall payoff (Axelrod 1984). However, strategies that are exploitative can also be collectively stable, including Graaskamp and AllD.[7] If the choice set is restricted to the nine collectively stable strategies, then tit for tat remains the knowledge-induced equilibrium. Tit for tat also is the unique knowledge-induced equilibrium if one removes the two unconditional strategies AllD and AllC, which were added to Axelrod's original strategy set.

DISCUSSION

The strong coordinating attributes of tit for tat suggest that its simple form of reciprocity has a special place in the cognitive organization of strategies. Tit for tat, with its simple and clear reciprocity rule, emerged as the salient coordination solution of the knowledge organization of the set of strategies. This finding may explain the prominence of tit for tat in studies of social exchange, despite its numerous shortcomings from a purely theoretical perspective. In addition, even the second- and third-place contenders, namely Joss, Shubik, and Friedman, are close variations on tit for tat's simple logic. If tit for tat is removed from the set, then Friedman is the maximum likelihood choice with Shubik as a close runner-up. Both Friedman and Shubik rely on tit for tat's simple reciprocity rule but incorporate stronger punishment threats in the event of defection. In addition, unlike Joss, both Friedman and Shubik are collectively stable strategies. Yet, of all these close contenders, tit for tat incorporates the most cognitively simple and identifiable punishment threat. If tit for tat does hold a special place in the cognitive organization of reciprocity strategies, it may be related to its simplicity (Axelrod 1984).

However, these findings are only a first step in considering the coordinating power of mental representations in social exchange. The results presented here are based only on the set of strategies from Axelrod's (1980) first tournament rather than all possible equilibrium strategies. But extending the strategy set has implementation hurdles, and it is impossible to consider the theoretically infinite set of conditionally cooperative strategies.[8] One of the assumptions of a knowledge structure approach is that it is not necessary to consider all possible strategies but only those that have particular social meaning in a given context. The extent to which a knowledge structure is shared may vary in different contexts and across different groups. Communication and social interaction may play an important role in invoking a common emphasis frame to yield shared representations. Many experimental studies find that preplay communication leads to higher levels of cooperation in prisoner's dilemma contexts (e.g., Dawes, McTavish, and Shaklee 1977; Orbell, van de Kragt, and Dawes 1988; Sally 1995). There is also simulation evidence that social interaction leads to a convergence of structures of knowledge (e.g., Kennedy 1998). Although there are many conjectures as to why communication matters, such as altering expectations of others' behavior, promoting coordination, creating norms, and ensuring common knowledge about the game (Majeski and Fricks 1995; Kerr and Kaufman-Gilliland 1994), the precise intervening role of communication remains unclear. Furthermore, the role of communication is a puzzle because, theoretically, any communication in a prisoner's dilemma game is simply "cheap talk" that is nonbinding on the players. The results of this article suggest a role for communication in creating a convergence of the knowledge representations of the set of strategies and, in this way, altering expectations, promoting coordination, and creating norms. This conjecture may help account for why experimental findings on communication and cooperation depend on the type of communication: experiments with a minimal amount of communication, such as those in which communication is limited to proposed contributions without any face-to-face discussion, find no help from communication (e.g., Wilson and Sell 1997). Such limited communication would play no intervening role in establishing the shared understandings of strategies needed to overcome the coordination problem.

The fact that a single reciprocity strategy emerged as a knowledge-induced equilibrium in the coordination of strategies suggests the potential importance of cognitive structures in achieving the mutual coordination necessary for social exchange. Social exchange behavior is universal across all human cultures yet rare among other species (Axelrod and Hamilton 1981). Recent research has even identified the prisoner's dilemma game among the most noncognitive of life forms: RNA viruses; but infections based on groups of viruses do not achieve the greater fitness payoffs of coordinated cooperation (Turner and Chao 1999). The conjunction of all this evidence suggests a role for cognitive structures, in addition to social constraints and institutional structures, in achieving the coordination necessary for mutual cooperation and social exchange.

APPENDIX
Strategy Descriptions and Classifier Coding

Block	*Bit Position*	*Description*	*Coding*
1	1-2	How does the strategy start the game?	C = 00, .5C = 01, D = 11
2	3	Does the strategy have a special string of cooperations at the start of the game?	No = 0, yes = 1
3	4-5	If so, what is the start sequence?	4C = 00, 10C = 01, 11C = 10, Nyd1 = 11
4	6	Which histories are used?	Other = 0, both = 1
5	7-8	What is the length of previous plays that determines subsequent round play?	1 = 00, 3 = 01, 10 = 10, all = 11
6	9	Does the round of play matter (with the exception of start sequences in Block 3)?	No = 0, yes = 1
7	10	Is the strategy forgiving? (Is the other's choice of D responded to with AllD?)	No = 0, yes = 1
8	11	If the other defected on the previous move, what is the strategy response?	C = 0, D = 1
9	12-14	If no prescription from Block 8 (either because other cooperated or no simple response to D), what is the strategy response?	C = 000, D = 011, .5C = 001, .9C = 010, FldC = 100, DwnC = 101, TlkC = 110, CDct = 111
10	15	Else if no prescription from Block 8 and 9, then what is strategy response?	Grf = 0, Nyd2 = 1
11	16	Does the strategy employ a check of the other strategy?	No = 0, yes = 1
12	17-18	If so, what is that check?	FS = 00, SR = 01, Gk = 10

Table abbreviations are as follows:

Nyd1: Tit for tat on first three moves, except that if it was the only one to cooperate on the first move and the only one to defect on the second move, it defects on the third move.
FldC: Probability of C is decreased incrementally to .5 by round 200.
DwnC: Probability of C is based on probability estimates of other's play.
TlkC: Probability of C is 10% less than if the other player cooperated on the preceding 10 moves.
CDct: Cooperation is reduced based on count of each departure by other from mutual cooperation (CD).
Grf: Cooperate with probability 2/7 if players chose different actions on previous move, else cooperate.
Nyd2: Choice determined from weighted point system on other's previous three choices.
FS: Gives the other player a "fresh start" (two cooperations and then play as if the game just started) if the number of defections is three standard deviations away from random, other player is 10 or more points behind, other player has not just started a run of defections, and it is at least 20 moves since a fresh start.
SR: Checks every 15 moves whether other strategy is random.
Gk: Defects on round 51, plays 5 rounds of tit for tat, then checks if other strategy is random, tit for tat, or own twin.

Strategy descriptions are as follows:

AllC: Always cooperates. (00 0 ## # ## 0 # # 000 # 0 ##)

AllD: Always defects. (11 0 ## # ## 0 # # 011 # 0 ##)

Davis: Cooperates on the first 10 rounds and continues cooperation until the other player defects, in which case it defects until the end of the game. (00 1 01 1 00 0 1 1 000 # 0 ##)

Downing: Updates the conditional probabilities *p*(cooperation by other | cooperation by self) and *p*(cooperation by other | defection by self) over the history of play and selects its choice to maximize its long-term expected payoff. Initially, both conditional probabilities are assumed to be .5. (01 0 ## 0 00 0 0 # 101 # 0 ##)

Feld: Cooperates on the 1st round and thereafter defects once following a defection by the opponent and cooperates following the other player's cooperation with probability beginning with 1.0 and decreasing to .5 by the 200th round. (00 0 ## 0 00 1 0 1 100 # 0 ##)

Friedman: Cooperates until the other player defects and then defects until the end of the game. (00 0 ## 1 00 0 1 1 000 # 0 ##)

Graaskamp: Follows a tit-for-tat strategy for 50 rounds, defects on round 51, then plays 5 more rounds of tit for tat. A check is then made to see if the opponent is playing random (in which case it switches to AllD), or playing tit for tat or analogy or is its own twin (in which case it responds with tit for tat). Otherwise, it randomly defects every 5 to 15 rounds. (00 0 ## 1 11 1 0 1 000 # 1 10)

Grofman: If the players did different things on the previous round, this rule cooperates with probability 2/7. Otherwise, this strategy always cooperates. (00 0 ## 1 00 0 0 # ### 0 0 ##)

Joss: Cooperates 90% of the time after a cooperation by the other player and always defects after a defection by the other player. (00 0 ## 0 00 0 0 1 010 # 0 ##)

Nydegger: Begins with tit for tat for the first three rounds, except that if it was the only one to cooperate on the first round and the only one to defect on the second round, it defects on the third round. After the third round, its choice is determined from the three preceding outcomes in the following manner. Let *A* be the sum formed by counting the other's defection as 2 points and one's own as 1 point and giving weights of 16, 4, and 1 to the preceding three moves in chronological order. Nydegger defects only when *A* equals 1, 6, 7, 17, 22, 23, 26, 29, 30, 31, 33, 38, 39, 45, 49, 54, 55, 58, or 61. (00 1 11 1 01 0 0 # ### 1 0 ##)

Random: Cooperates and defects with equal probability. (01 0 ## # ## 0 # # 001 # 0 ##)

Shubik: Cooperates until the other player defects and then defects once. If the other player defects again after cooperation is resumed, then Shubik defects twice. In general, the length of retaliation is increased by one for each departure from mutual cooperation. (00 0 ## 1 11 0 0 1 111 # 0 ##)

Stein and Rapoport: Cooperates on the first 4 rounds, then follows a tit-for-tat strategy, checking every 15 rounds to see if the other player is random. (00 1 00 0 11 1 0 1 000 # 1 01)

Tideman and Chieruzzi: Follows as in the Shubik strategy, except gives the other player a "fresh start" if the other player is 10 or more points behind, has not just started a run of defections, it has been at least 20 moves since a fresh start, and the number of defections differs from a 50-50 random generator by at least three standard deviations. A fresh start involves two cooperations and then play as if the game had just started. (00 ## 1 11 1 0 1 111 # 1 00)

Tit for tat: Cooperates on the first round and then does whatever the other player did on the previous round. (00 0 ## 0 00 0 0 1 000 # 0 ##)

Tullock: Cooperates on the first 11 rounds, then cooperates 10% less than the other player cooperated on the preceding 10 rounds. (00 1 10 0 10 0 0 # 110 # 0 ##)

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