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The Use and Misuse of Game Theory

Can this fashionable technique really be used to solve the problems of human conflict? The author believes that it cannot, but that it can teach us what to do in order to solve such problems rationally

by Anatol Rapoport

We live in an age of belief—belief in the omnipotence of science. This belief is bolstered by the fact that the problems scientists are called on to solve are for the most part selected by the scientists themselves. For example, our Department of Defense did not one day decide that it wanted an atomic bomb and then order the scientists to make one. On the contrary, it was Albert Einstein, a scientist, who told Franklin D. Roosevelt, a decision maker, that such a bomb was possible. Today, in greater measure than ever before, scientists sit at the decision makers' elbows and guide the formulation of problems in such a way that scientific solutions are feasible. Problems that do not promise scientific solutions generally tend to go unformulated. Hence the faith in the omnipotence of science.

The self-amplifying prestige of science among decision makers has been further amplified in this period by the popularization of a scientific aid to the task of decision making itself. This is game theory—a mathematical technique for the analysis of conflict first propounded by the late John Von Neumann in 1927 and brought to wide notice by Von Neumann and Oskar Morgenstern in 1944 in a book entitled *Theory of Games and Economic Behavior*. Now, game theory is an intellectual achievement of superlative originality and has opened a large new field of research. Unfortunately this is not the way game theory has been embraced in certain quarters where Francis Bacon's dictum "Knowledge is power" is interpreted in its primitive, brutal sense. The decision makers in our society are overwhelmingly preoccupied with power conflict, be it in business, in politics or in the military. Game theory is a "science of conflict." What could this new science be

but a reservoir of power for those who get there fastest with the mostest?

A thorough understanding of game theory should dim these greedy hopes. Knowledge of game theory does not make any one a better card player, businessman or military strategist, because game theory is not primarily concerned with disclosing the optimum strategy for any particular conflict situation. It is concerned with the logic of conflict, that is, with the theory of strategy. In this lies both the strength and the limitation of the technique. Its strength derives from the powerful and intricate mathematical apparatus that it can bring to bear on the strategic analysis of certain conflict situations. The limitations are those inherent in the range of conflicts to which this analysis can be successfully applied.

No one will doubt that the logic of strategy does not apply to certain conflicts. For example, there are no strategic considerations in a dogfight. Such a conflict is better thought of as being a sequence of events, each of which triggers the next. A growl is a stimulus for a countergrowl, which in turn stimulates the baring of teeth, sudden thrusts and so on. Signals stimulate postures; postures stimulate actions. Human quarrels, where symbolic rather than physical injuries are mutually stimulated, are frequently also of this sort. Conflicts of this kind can be called fights. The motivation in a fight is hostility. The goal is to eliminate the opponent, who appears as a noxious stimulus, not as another ego, whose goals and strategies, even though hostile, must be taken into account. Intellect, in the sense of calculating capacity, foresight and comparison of alternative courses of action, need not and usually does not play any part in a fight.

Game theory applies to a very different type of conflict, now technically called a game. The well-known games such as poker, chess, ticktacktoe and so forth are games in the strict technical sense. But what makes parlor games games is not their entertainment value or detachment from real life. They are games because they are instances of formalized conflict: there is conflict of interest between two or more parties; each party has at certain specified times a range of choices of what to do prescribed by the rules; and the outcome representing the sum total of choices made by all parties, and in each case involving consideration of the choice made by or open to the other parties, determines an assignment of pay-offs to each party. By extension, any conflict so conducted falls into the category of games, as defined in game theory. Nor does it matter whether the rules are results of common agreement, as in parlor games, or simply of restraints imposed by the situation. Even if no rules of warfare are recognized, a military situation can still be considered as a game if the range of choices open to each opponent at any given stage can be exactly specified.

Let us see how chess and poker each fulfill these requirements. In chess the conflict of interest is, of course, implied
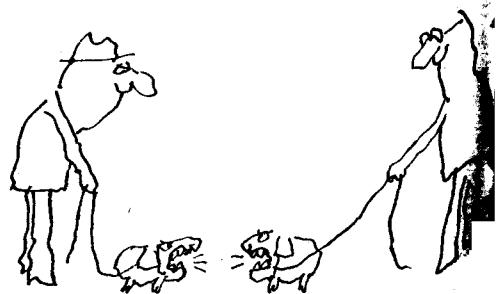
Bark and counterbark

in each player's desire to win. The range of choices consists for each player of all the legal moves open to him when it is his turn to move. The outcome is determined by all the choices of both players. The pay-offs are usually in psychological satisfaction or dissatisfaction. In poker the situation is much, but not entirely, the same. The choices are (at specified times) whether or not to stay in; which cards, if any, to throw off; whether or not to raise and by how much and so on. The outcome of each round is the designation of one of the players as the winner. Pay-offs are usually in money.

Poker differs from chess in one important respect. In a poker game there is an extra (invisible) player, who makes just one choice at the beginning of each round. This choice is important in determining the outcome, but the player who makes it has no interest in the game and does not get any pay-off. The player's name is Chance, and his choice is among the nearly 100 million trillion trillion trillion trillion trillion (10^{68}) arrangements of the deck at the beginning of each round. Chance makes no further choices during the round; the rest is up to the players. One can argue that Chance continues to interfere, for example by causing lapses of memory, directing or misdirecting the attention of the players and so forth. But game theory is concerned only with what perfect players would do.

Although Chance may thus play a part, the game as defined by game theory is clearly distinguished from gambling as treated by the much older and better-known mathematics of gambling. The latter has considerable historical importance, since it is in the context of gambling theory that the mathematical theory of probability was first developed some 300 years ago. This theory has since been incorporated into all branches of science where laws of chance must be taken into account, as in the physics of small particles, genetics, actuarial science, economics, experimental psychology and the psychology of mass be-

havior. For the gambler the mathematical theory of probability makes possible a precise calculation of the odds. This often calls for considerable mathematical sophistication. It is irrelevant, however, to the playing of the game; it is relevant only in deciding whether or not to play. The gambling problem is solved when the odds of the possible outcomes have been calculated. If there are several such outcomes, the gains or losses associated with each are multiplied by the corresponding probabilities and the products are added (with proper signs attached). The resulting number is the expected gain; that is, what can be reasonably expected over a long series of bets when the bets are placed according to the odds offered. A rational gambler is one who accepts or offers the gambles in such a way as to maximize his expected gain. All gambling houses are rational gamblers. That is why they stay in business.

The inadequacy of gambling theory as a guide in a true game is shown clearly in the well-known fact that the rational gambler is likely to meet with disaster in a poker game. The rational gambler will make his decisions strictly in accordance with the odds. He will never bluff, and he will bet in proportion to the strength of his hand. As a result he will betray his hand to his opponents, and they will use the information to his disadvantage.

Gambling theory is of even less use to the ticktacktoe player. Ticktacktoe is a game in which there is a best move in every conceivable situation. Chance, we know, is not involved at all in some games. To be sure, chance is involved in all card games but, as the example of poker shows, something else is involved, namely a strategic skill that is not part of gambling theory at all.

Consider what goes on in the mind of a chess player: If I play Knight to Queen's Bishop's 4, thus threatening his rook, he can reply Rook to King's 2, check. In that case I have the choice of either interposing the Bishop or King


The omnipotent scientist

to Queen's 1. On the other hand, he can ignore the threat to the rook and reply with a counterthreat by Bishop to Knight's 5, in which case I have the following choices . . .

The stronger the player, the longer this chain of reasoning is likely to be. But because of the limitations on how much we can hold in our minds at one time, the chain of reasoning must stop somewhere. For the chess player it stops a few moves ahead of the situation at hand, at a set of possible new situations among which he must choose. The one situation that will actually occur depends partly on his own choices and partly on the choices available to the opponent (over whom the first player has no control). Two decisions are involved in the choice of action: first, which situations may actually occur? Second, which of all those situations is to be preferred?

Now, these questions can be answered without ambiguity if the game is thought out to the end. In a game such as chess, however, it is out of the question to foresee all the alternatives to the end (except where checkmates or clear wins are foreseen as forced). The good chess player then does the next best thing: he calculates the relative values of the various possible future positions according to his experience in evaluating such positions. How then does he know which position will be actually arrived at, seeing that he controls only his own moves, not those of the opponent? Chess players recognize two chess philosophies.
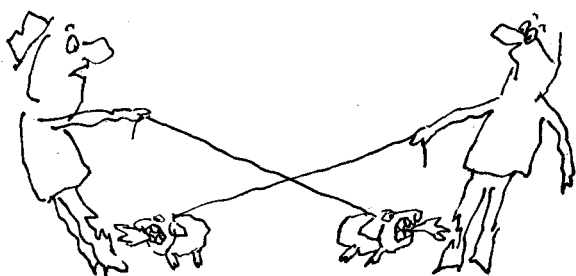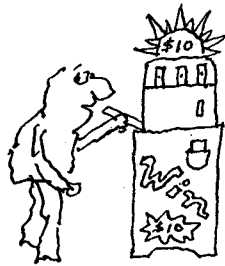

Bite and counterbite
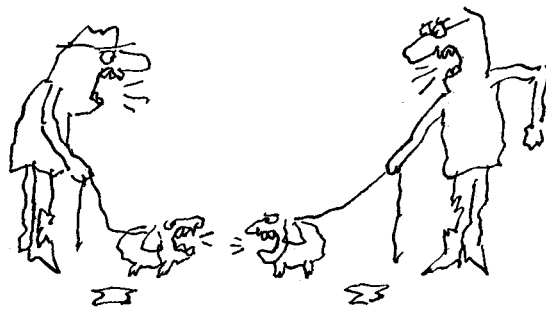
Escalated conflict
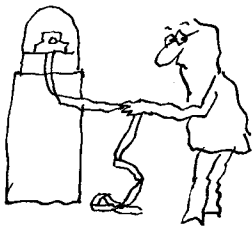
Playing the stock market or a slot machine involves no game theory

One is "playing the board," the other is "playing the opponent."

Playing the opponent makes chess akin to psychological warfare. The great chess master José Capablanca tells in his memoirs of an incident that illustrates the drama of such conflicts. In a tournament in 1918 he was matched with Frank J. Marshall, the U.S. champion. Marshall offered an unexpected response to Capablanca's accustomed opening attack, and the play proceeded not at all in line with the usual variations of this opening. Capablanca suspected that Marshall had discovered a new variation in the attack and had kept this knowledge as a secret weapon, to be used only at the most propitious time, namely in an international tournament with the eyes of the chess world on his play against a truly formidable opponent. Capablanca had been picked as the victim of the new strategy.

"The lust of battle, however," Capablanca continues, "had been aroused within me. I felt that my judgment and skill were being challenged by a player who had every reason to fear both (as shown by the records of our previous encounters), but who wanted to take advantage of the element of surprise and of the fact of my being unfamiliar with a

Psychological warfare in chess

Advanced psychological warfare in chess

thing to which he had devoted many nights of toil. . . . I considered the position then and decided that I was in honor bound . . . to accept the challenge."

He did and went on to win the game. Capablanca's decision was based on taking into account his opponent's thought processes, not only those pertaining to the game but also Marshall's ambitions, his opinion of Capablanca's prowess, his single-mindedness and so on. Capablanca was playing the opponent.

Although the drama of games of strategy is strongly linked with the psychological aspects of the conflict, game theory is not concerned with these aspects. Game theory, so to speak, plays the board. It is concerned only with the logical aspects of strategy. It prescribes the same line of play against a master as it does against a beginner. When a strategic game is completely analyzed by game-theory methods, nothing is left of the game. Ticktacktoe is a good example. This game is not played by adults because it has been completely analyzed. Analysis shows that every game of ticktacktoe must end in a draw. Checkers is in almost the same state, although only exceptionally good players know all the relevant strategies. A generation ago it was thought that chess too was approaching the "draw death." But new discoveries and particularly the introduction of psychological warfare into chess, notably by the Russian masters, has given the game a reprieve. Nevertheless H. A. Simon and Allen Newell of the Carnegie Institute of Technology have seriously predicted that within 10 years the world's chess champion will be an electronic computer. The prediction was made more than three years ago. There is still a good chance that it will come true.

Is the aim of game theory, then, to reveal the logic of every formalized game so that each player's best strategy is discovered and the game as a whole is killed because its outcome in every instance will be known in advance? This is by no means the case. The class of games for which such an analysis can

be carried through even in principle, let alone the prodigious difficulty of doing it in practice, is only a very small class.
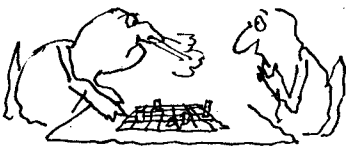
Games of this class are known as games of perfect information. They are games in which it is impossible to have military secrets. Chess is such a game. Whatever the surprise Marshall thought he had prepared for Capablanca, he was not hiding something that could not be discovered by any chess player. He only hoped that it would be overlooked because of human limitations.

Not all games are games of perfect information. Poker is definitely not such a game. The essence of poker is in the circumstance that no player knows the entire situation and must be guided by guesses of what the situation is and what the others will do. Both chess and poker are "zero-sum" games in the sense that what one player wins the other or others necessarily lose. Not all games are of this sort either.

To understand the differences among these various classes of games, let us look at some examples from each class. The essential idea to be demonstrated is that each type of situation requires a different type of reasoning.

An improbably elementary situation in business competition will serve to illustrate the class of games of perfect information. The situation is otherwise a two-person zero-sum game. The Castor Company, an old, established firm, is being squeezed by Pollux, Incorporated, an aggressive newcomer. The Castor people guide their policies by the balance sheet, which is projected one year ahead. The Pollux people also guide their policies by a balance sheet, not their own but the Castor Company's. Their aim is to put Castor out of business, so they consider Castor's losses their gains and vice versa, regardless of what their own balance shows. Both are faced with a decision, namely whether or not to undertake an extensive advertising campaign. The outcome depends on what both firms do, each having control over only its own decision. Assume, however, that both firms have enough information to know what the outcomes will be, given both decisions [*see matrix at left in bottom illustration on page 112*].

From Castor's point of view, a better or a worse outcome corresponds to each of its decisions, depending on what Pollux does. Of the two worse outcomes associated with Castor's two possible decisions, $3 million in the red and $1 million in the red (both occurring if Pollux advertises), clearly the second is preferred. Castor's manager now puts him-

self into the shoes of Pollux' manager and asks what Pollux would do if Castor chose the lesser of the two evils. Clearly Pollux would choose to advertise to prevent the outcome that would be better for Castor ($1 million in the black). Getting back into his own shoes, Castor's manager now asks what he would do knowing that this was Pollux' decision. Again the answer is advertise. Exactly similar reasoning leads Pollux to its decision, which is advertise. Each has chosen the better of the two worse alternatives. In the language of game theory this is called the minimax (the maximum of the minima). This solution is always prescribed no matter how many alternatives there are, provided that the gains of one are the losses of the other and provided that what is the "best of the worst" for one is also the "best of the worst" for the other. In this case the game has a saddle point (named after the position on the saddle that is lowest with respect to front and back and highest with respect to right and left). Game theory shows that whenever a saddle point exists, neither party can improve the outcome for itself (or worsen it for the other). The outcome is forced, as it is in ticktacktoe.

The next situation is quite different. It is a two-person zero-sum game, again involving the choice of two strategies on each side. In this case, however, the choices must be made in the absence of the information that guides the opponent's decision. Appropriately this is a military situation enveloped in the fog of battle.

A commander of a division must decide which of two sectors to attack. A breakthrough would be more valuable in one than in the other, but the more valuable sector is also likely to be more strongly defended. The defending commander also has a problem: which sector to reinforce. It would seem obvious that the more critical sector should be reinforced at the expense of the secondary one. But it is clear to the defending commander that the problem is more complicated. Secrecy is of the essence. If he does exactly what the enemy expects him to do, which is to reinforce the critical sector, will this not be to the enemy's advantage? Will not the attacker, knowing that the important sector is more strongly defended, attack the weaker one, where a breakthrough, even though less valuable, is more certain? Should the defender therefore not do the opposite of what the enemy expects and reinforce the secondary sector, since that

is where the enemy, wishing to avoid the stronger sector, will probably attack? But then is not the enemy smart enough to figure this out and so attack the primary center and achieve a breakthrough where it counts?

The attacking commander is going through the same tortuous calculations. Should he attack the secondary sector because the primary one is more likely to be strongly defended or should he attack the primary one because the enemy expects him to avoid it?

In despair the attacking commander calls in a game theorist for consultation. If the game theorist is to help him, the

general must assign numerical values to each of the four outcomes; that is, he must estimate (in relative units) how much each outcome is "worth" to him. He assigns the values shown in the top illustration on the next page. Working with these figures, the game theorist will advise the general as follows: "Roll a die. If ace or six comes up, attack sector 1, otherwise attack sector 2."

If the defending commander assigns the same values (but with opposite signs, since he is the enemy) to the four outcomes, his game theorist will advise him to throw two pennies and reinforce sector 1 if they both come up heads,
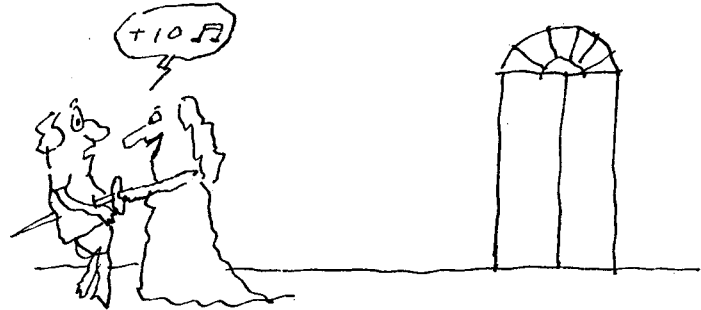
Game theory in "Tosca": Tosca double-crosses Scarpia
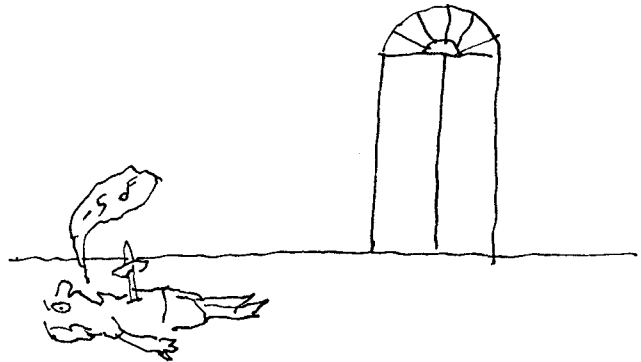
Scarpia derives satisfaction from the thought of what is going to happen

Tosca and Cavaradossi discover the double double cross

TWO-PERSON ZERO-SUM GAME of an attacking (*A*) and a defending commander (*D*), in which neither possesses the information that guides his opponent's decisions, is summarized in these three matrices. The first commander has the choice of attacking a primary sector (*A₁*) or a secondary sector (*A₂*). The matrix at left shows the values he assigns to the four possibilities. The second commander has the choice of defending either sector. The matrix at center shows his assigned values. As the number of diagonal lines in each matrix square indicates, the first commander should decide by chance, using two-to-one odds in favor of the secondary sector; likewise for the defending commander, except that the odds are three to one. These results are combined in the matrix at right.

otherwise he should reinforce sector 2.

The solutions seem bizarre, because we think of tossing coins to make decisions only in matters of complete indifference. To be sure, a tossed-coin decision is sometimes used to settle an argument, but we do not think of such decisions as being rational and do not hire experts to figure them out. Nevertheless, the game theorists' decisions are offered not only as rational decisions but also as the best possible ones under the circumstances.

To see why this is so, imagine playing the game of button-button. You hide a button in one hand and your opponent tries to guess which. He wins a penny if he guesses right and loses a penny if he guesses wrong. What is your best pattern of choices of where to hide the button in a series of successive plays? You will certainly not choose the same hand every time; your opponent will quickly find this out. Nor will you alternate between the two hands; he will find this out too. It is reasonable to conclude (and it can be proved mathematically) that the best pattern is no pattern. The best way to ensure this is to abdicate your role as decision maker and let chance decide for you. Coin tossing as a guide to strategy is in this case not an act of desperation but a rational policy.

In the button-button game the payoffs are exactly symmetrical. This is why decisions should be made by a toss of a fair coin. If the pay-offs were not symmetrical—for example, if there were more advantage in guessing when the coin was in the right hand—this bias would have to be taken into account. It would be reflected in letting some biased chance device make the decision. Game theory provides the method of computing the bias that maximizes the long-run expected gain.

ZERO-SUM AND NONZERO-SUM GAMES are represented in these three game-theory matrices. The matrix at left is that of the two-person zero-sum game of perfect information discussed in the text. The matrix tabulates the results for Castor Company (in millions of dollars) of any combination of decisions; e.g., if Castor and Pollux, Incorporated, both advertise (*Cy and Py*), Castor loses $1 million. For Pollux, which will decide on the basis of the effect on Castor, this is a positive pay-off. Tosca and Scarpia are involved in a nonzero-sum game (also discussed in the text), that is, a gain for one does not imply a loss for the other. Tosca's line of reasoning can be determined from the matrix at center: if she keeps her bargain with Scarpia (*Tk*), then she loses everything if he double-crosses her (*Sd*); her gain is greatest and her loss least if she double-crosses him (*Td*). Scarpia, as the matrix at right indicates, reasons along the same line, in reverse. They both lose equally; if they had trusted each other, they would have gained equally.

The attacker's game theorist, then, has figured out that the attacker stands the best chance if he allows chance to decide, using two-to-one odds in favor of sector 2. This is the meaning of rolling a die and allowing four sides out of six to determine the second sector. This is the best the attacker can do against the best the defender can do. The defender's best is to let chance decide, using three-to-one odds in favor of sector 2. Game theory here prescribes not the one best strategy for the specific occasion but the best mixture of strategies for this kind of occasion. If the two commanders were confronted with the same situation many times, these decisions would give each of them the maximum pay-offs they can get in these circumstances if both play rationally.

At this point one may protest that it is difficult, if not impossible, to assign numerical values to the outcome of real situations. Moreover, identical situations do not recur, and so the long-run expected gain has no meaning. There is much force in these objections. We can only say that game theory has gone just so far in baring the essentials of strategic conflict. What it has left undone should not be charged against it. In what follows some further inadequacies of game theory will become apparent. Paradoxically, in these inadequacies lies most of the value of the theory. The shortcomings show clearly how far strategic thinking can go.

In the next class of games to be illustrated there are choices open to the two parties where the gain of one does not imply loss for the other and vice versa. Our "nonzero-sum" game is a tale of lust and betrayal. In Puccini's opera *Tosca* the chief of police Scarpia has condemned Tosca's lover Cavaradossi to death but offers to save him in exchange for Tosca's favors. Tosca consents, the agreement being that Cavaradossi will go through a pretended execution. Scarpia and Tosca double-cross each other. She stabs him as he is about to embrace her, and he has not given the order to the firing squad to use blank cartridges.

The problem is to decide whether or not it was to the best advantage of each party to double-cross the other. Again we must assign numerical values to the outcome, taking into account what each outcome is worth both to Tosca and to Scarpia [see two matrices at right in bottom illustration on opposite page].

The values, although arbitrary, present the situation reasonably. If the bargain is kept, Tosca's satisfaction of getting her lover back is marred by her surrender to the chief of police. Scarpia's satisfaction in possessing Tosca will be marred by having had to reprieve a hated rival. If Tosca double-crosses Scarpia and gets away with it, she will win most (+ 10) and he will lose most (− 10), and vice versa. When both double-cross each other, both lose, but not so much as each would have lost had he or she been the sucker. For example, the dying Scarpia (we assume) derives some satisfaction from the thought of what is going to happen just before the final curtain, when Tosca rushes to her fallen lover and finds him riddled with bullets.

Let us now arrive at a decision from Tosca's point of view: whether to keep the bargain or to kill Scarpia. Tosca has no illusions about Scarpia's integrity. But she is not sure of what he will do, so she considers both possibilities: If he keeps the bargain, I am better off double-crossing him, since I will get Cavaradossi without Scarpia if I do and Cavaradossi with Scarpia if I don't. If he double-crosses me, I am certainly better off double-crossing him. It stands to reason that I should kill him whatever he does.

Scarpia reasons in exactly the same way: If she keeps the bargain, I am better off double-crossing her, since I will get rid of Cavaradossi if I do and have to put up with him if I don't. If she double-crosses me, I certainly should see to it that I am avenged. The execution, therefore, must go on.
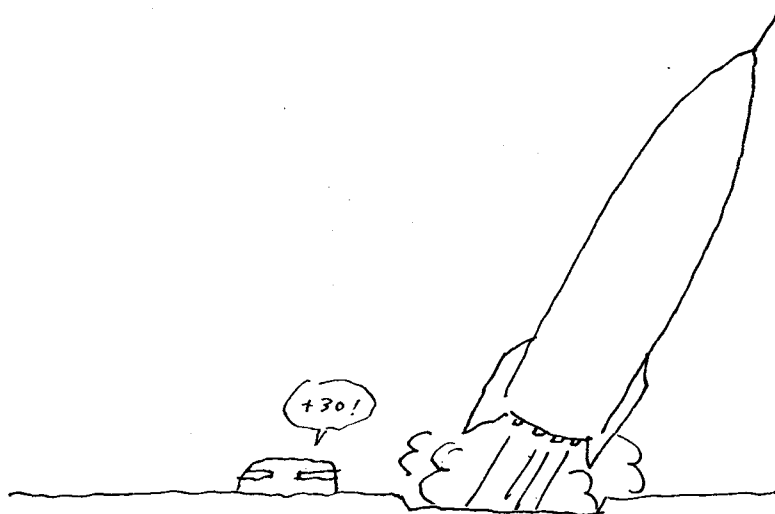
The result is the denouement we know. Tosca and Scarpia both get − 5. If they had trusted each other and had kept the trust, each would have got + 5.

The shortcoming of strategic thinking becomes obvious in this example. Evidently more is required than the calculation of one's own pay-offs if the best decisions are to be made in conflict situations. Game theory can still treat the foregoing case satisfactorily by introducing the notion of a coalition. If Tosca and Scarpia realize that the interests of both will be best served if both keep the bargain, they need not both be losers. Coalitions, however, bring headaches of their own, as will be seen in the next example.
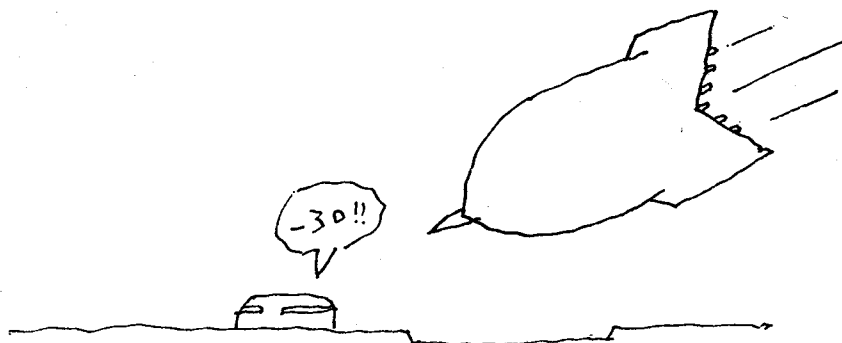
Abe, Bob and Charlie are to divide a dollar. The decision as to how to divide it is to be by majority vote. Abe and Bob form a coalition and agree to split the dollar evenly between them and so freeze Charlie out. The rules of the game allow bargaining. Charlie approaches Bob
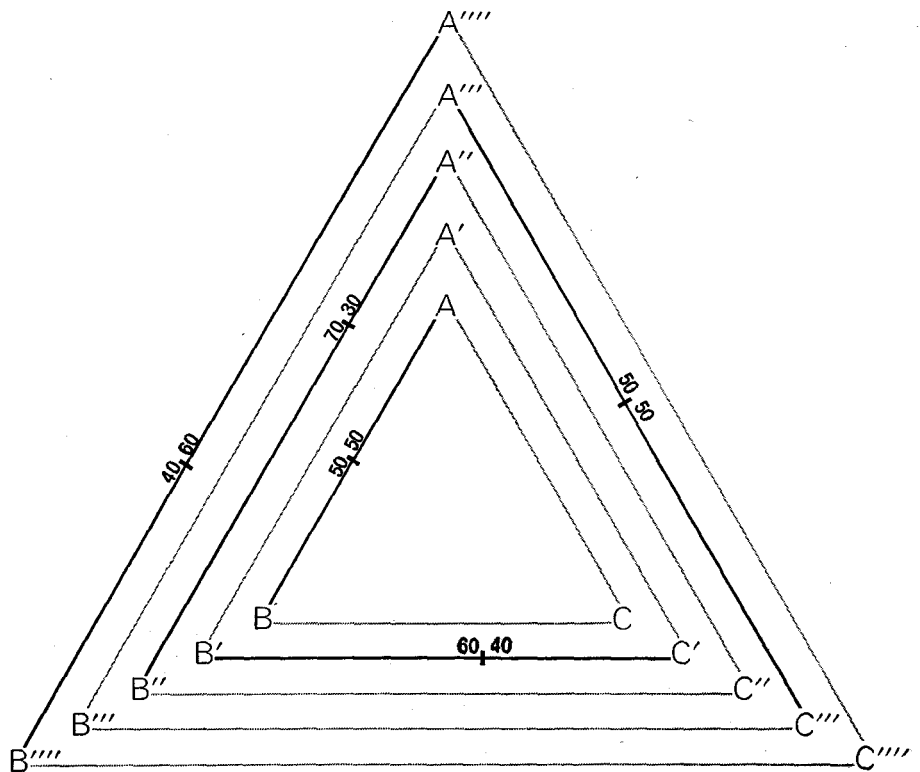
COALITION GAME involves splitting a dollar among three individuals; the split is decided by majority vote. Abe and Bob (*A and B*) form a coalition that excludes Charlie (*C*). Charlie then (*C'*) offers Bob (*B'*) 60 cents of the dollar, and so on. Any division is inherently unstable because two can always do better for themselves than can three, and two can enforce any division. No game-theory strategy will guarantee a division satisfactory to all.

Maximum in the military application of game theory

Minimum

of the worst outcomes. When both choose the minimax, neither firm can improve its position. Had one of the generals used such a decision, he would have been clearly at a disadvantage. Military secrecy introduces an element of randomness to confound the enemy and brings in a different kind of reasoning. Such reasoning would have been useless in the Castor and Pollux example, because in their case each knew what the other's best decision had to be, and this knowledge made no difference to either. The difference between the two situations is immediately apparent to the game theorist. In the first case the minimax choice of one player is also the minimax choice of the other, in the second case it is not.

Consider the Tosca-Scarpia game. Here both parties have the same minimax choice, which, in fact, they choose. The outcome is bad for both. Why is this? Again the answer is clear to the game theorist. Tosca and Scarpia were playing the game as if it were a zero-sum game, a game in which what one party wins the other necessarily loses. If we examine the pay-offs, we find that this is not the case. Both parties could have improved their pay-offs by moving from the minimax solution to the coalition solution (keeping the bargain and getting + 5 each). Life would be simple if advantage in conflicts could always be obtained by forming and keeping proper coalitions. But the dilemma plaguing Abe, Bob and Charlie deprives us of that hope also. Moreover, both the Tosca-Scarpia game and the divide-the-dollar game reveal that decisions based on calculated self-interest can lead to disaster.

Whether game theory leads to clearcut solutions, to vague solutions or to impasses, it does achieve one thing. In bringing techniques of logical and mathematical analysis to bear on problems involving conflicts of interest, game theory gives men an opportunity to bring conflicts up from the level of fights, where the intellect is beclouded by passions, to the level of games, where the intellect has a chance to operate. This is in itself no mean achievement, but it is not the most important one. The most important achievement of game theory, in my opinion, is that game-theory analysis reveals its own limitations. Because this negative aspect is far less understood than the positive aspect, it will be useful to delve somewhat deeper into the matter.

The importance of game theory for decision making and for social science can be best understood in the light of the

with a proposition. He offers Bob 60 cents of the dollar if Bob will shift his vote to freeze Abe out. Abe does not like this arrangement, so he offers Bob 70 cents to shift his vote again to freeze Charlie out. Bob is about to rejoice in his good fortune, which he attributes to his bargaining shrewdness, when he notices that Abe and Charlie are off in a corner. Bob is shrewd enough to guess what they are discussing, and he is right. They are discussing the folly of respectively getting 30 cents and nothing when they have the power to freeze Bob out and split the dollar between them. In fact, they do this. Bob now approaches Abe hat in hand and offers him 60 cents if he will come back. The question is: Should Abe accept the offer?

The game-theory solutions to problems of this sort are extremely involved and need not be pursued here. Instead let us try to summarize in general terms the values and limitations of the game-theory approach to human conflict.

The value of game theory is not in the specific solutions it offers in highly simplified and idealized situations, which may occur in formalized games but hardly ever do in real life. Rather, the prime value of the theory is that it lays bare the different kinds of reasoning that apply in different kinds of conflict.

Let us go back to our examples and compare them. The decisions made by Castor and Pollux were clear-cut, and they were the best decisions on the basis of the knowledge at hand. As we have seen, both firms were guided by the principle of the minimax, choosing the best

history of science. Scientists have been able to avoid much futile squandering of effort because the very foundations of science rest on categorical statements about what cannot be done. For example, thermodynamics shows that perpetual-motion machines are impossible. The principles of biology assert the impossibility of a spontaneous generation of life and of the transmission of acquired characteristics; the uncertainty principle places absolute limits on the precision of certain measurements conducted simultaneously; great mathematical discoveries have revealed the impossibility of solving certain problems.

Absolute as these impossibilities are, they are not absolutely absolute but are so only in certain specific contexts. Progress in science is the generalization of contexts. Thus the conservation of mechanical energy can be circumvented by converting other forms of energy into mechanical energy. The simpler conservation law is violated, but it is re-established in a more general thermodynamic context. In this form it can again be seemingly violated, but it is again re-established in the still broader context of $E = mc^2$. Angles can be mechanically trisected by instruments more complicated than the straightedge and the compass. Life can probably be synthesized, but not in the form of maggots springing from rotting meat; acquired characteristics can probably be genetically transmitted, but not by exercising muscles.

The negative verdicts of science have often been accompanied by positive codicils. The power conferred by science, then, resides in the knowledge of what cannot be done and, by implication, of what can be done and of what it takes to do it.

The knowledge we derive from game theory is of the same kind. Starting with the simplest type of game, for example two-person zero-sum games with saddle points, we learn from game-theory analysis that the outcome of such games is predetermined. This leads to a verdict of impossibility: neither player can do better than his best. Once these bests are discovered, it is useless to play such a game. If war were a two-person zero-sum game with a saddle point, the outcome of each war could conceivably be calculated in advance and the war would not need to be fought. (The conclusion that wars need to be fought because they are not two-person zero-sum games with saddle points is not warranted!)
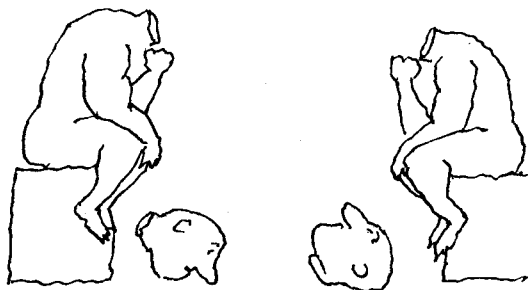
Examining now the two-person zero-sum game without a saddle point, we
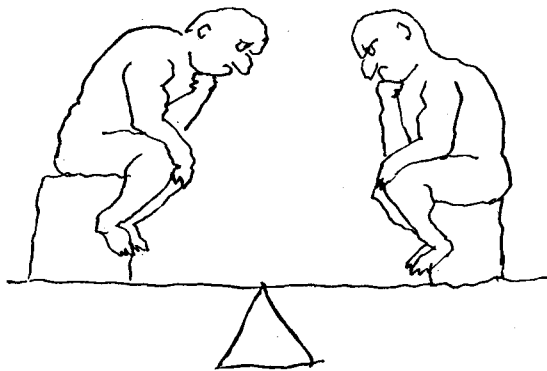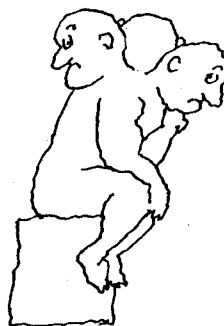

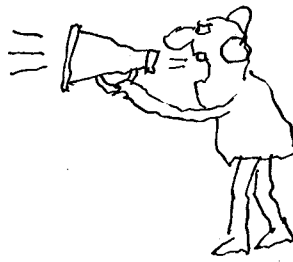*Strategic thinking in a two-person zero-sum situation with a saddle point*
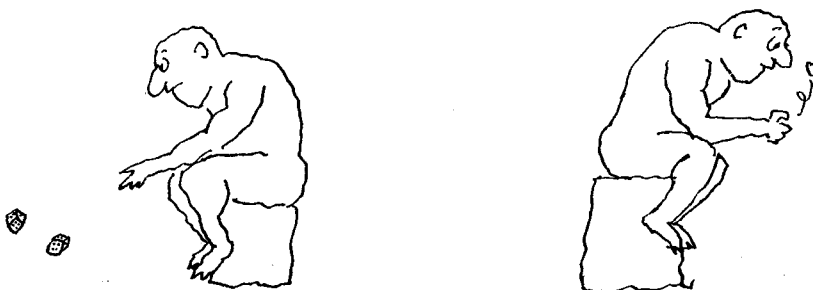
Strategic thinking in a two-person zero-sum situation without a saddle point

Strategic thinking in a two-person nonzero-sum situation

Strategic thinking in a three-person constant-sum situation with a coalition

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Communication is a prerequisite for the resolution of conflict

arrive at another verdict of impossibility: It is impossible to prescribe a best strategy in such a game. It is still possible, however, to prescribe a best mixture of strategies. The meaning of a strategy mixture and the advantage of using it can be understood only in a certain context, namely in the context of an expected gain. This in turn requires that our concept of preference be defined with a certain degree of specificity. To choose the best strategy in a saddle-point game it is necessary only to rank-order the preferences for the possible outcomes. To choose the best strategy mixture an interval scale (like that of temperature) must be assigned to our preferences. Unless this more precise quantification of preferences can be made, rational decisions cannot be made in the context of a game without a saddle point.

I have often wondered to what extent decision makers who have been "sold" on game theory have understood this last verdict of impossibility, which is no less categorical than the verdict on squaring the circle with classical tools. I have seen many research proposals and listened to long discussions of how hot and cold wars can be "gamed." Allowing for the moment that hot and cold wars are zero-sum games (which they are not!), the assignment of "utilities" to outcomes must be made on an interval scale. There is the problem. Of course, this problem can be bypassed, and the utilities can be assigned one way or another, so that we can get on with

the gaming, which is the most fun. But of what practical use are results based on arbitrary assumptions?

That is not all. By far the most important conflicts that plague the human race do not fit into the two-person zero-sum category at all. The Tosca-Scarpia game and the Abe-Bob-Charlie game are much more realistic models of human conflicts, namely dramas, in which individuals strive for advantage and come to grief. In these games there are neither pure nor mixed strategies that are best in the sense of guaranteeing the biggest pay-offs under the constraints of the game. No argument addressed individually to Tosca or to Scarpia will convince either that it is better to keep the bargain than to double-cross the other. Only an argument addressed to both at once has this force. Only collective rationality will help them to avoid the trap of the double double cross.

Similarly we can tell nothing to Abe, Bob or Charlie about how to behave to best advantage. We can only tell them collectively to settle the matter in accordance with some pre-existing social norm. (For example, they can take 33 cents apiece and donate one to charity.) This solution is based on an ethical principle and not on strategic considerations.

The role of social norms in games with more than two players was not missed by Von Neumann and Morgenstern. The importance of honesty, social responsibility and kindred virtues has been pointed out by sages since the dawn of history. Game theory, however,

gives us another perspective on these matters. It shows how the "hardheaded" analysis of conflicts (with which game theory starts) comes to an impasse, how paradoxical conclusions cannot be avoided unless the situation is reformulated in another context and unless other, extra-game-theory concepts are invoked. Thus acquaintance with these deeper aspects of game theory reveals that the poker game is not the most general or the most sophisticated model of conflict, nor the most relevant in application, as professional strategists often implicitly assume.

Game theory, when it is pursued beyond its elementary paradox-free formulations, teaches us what we must be able to do in order to bring the intellect to bear on a science of human conflict. To analyze a conflict scientifically, we must be able to agree on relative values (to assign utilities). We must learn to be perceptive (evaluate the other's assignment of utilities). Furthermore, in order to engage in a conflict thus formalized, we must be able to communicate (give a credible indication to the other of how we assign utilities to outcomes). At times we must learn the meaning of trust, or else both we and our opponents will invariably lose in games of the Tosca-Scarpia type. At times we must be able to convince the other that he ought to play according to certain rules or even that he ought to play a different game. To convince the other we must get him to listen to us, and this cannot usually be done if we ourselves do not listen. Therefore we must learn to listen in the broadest sense of listening, in the sense of assuming for a while the other's world outlook, because only in this way will we make sense of what he is saying.

All these skills are related not to know-how but to wisdom. It may happen that if we acquire the necessary wisdom, many of the conflicts that the strategy experts in their professional zeal insist on formulating as battles of wits (or, worse, as battles of wills) will be resolved of their own accord.
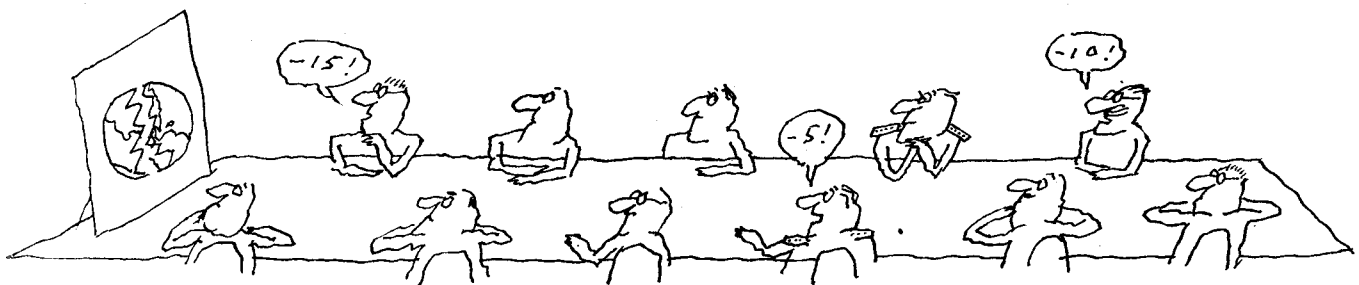
Another prerequisite is the assignment of utilities to outcomes

Blechman