COPING WITH COMPLEXITY AND UNCERTAINTY

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Contents

Summary

The computational and heuristic strategies used by decision makers to manage uncertainty in complex systems originated with the early landmark contributions of J. von Neumann. These contributions took the form of artificial intelligence and artificial life concepts, and then evolved more specifically into game theory, expert systems, neural networks, genetic algorithms and evolutionary computations, cellular automata, and techniques specific to the control of deterministic chaos. Psychological heuristics for the control of uncertainty in chaotic, and otherwise complex, organizational or economic systems take the form of tracking nonlinear dynamic patterns, parameter control, targeting, and forced periodicity. Problems in and challenges to the establishment of the external validity of expert systems and other decision-emulation programs are described.

1. Introduction

Decision theories and decision-support techniques and computer programs are almost universally designed to assist decision makers to maximize their decision outcomes and minimize decision errors. Decision theory and decision support are interesting and valuable endeavors because the decisions in question typically occur in situations where the information on which the decision is based is incomplete, error-prone, and changing over time. Additionally, decision makers are likely to pay for certainty; they do so by selecting decision choices that involve less risk, or by accessing the missing information sources that would serve to reduce uncertainty.

Uncertainty in decision making takes several forms: (a) The decision maker knows what the possible outcomes would be, knows the probabilities associated with each outcome, but is compelled to guess which of the outcomes will actually take place. (b) The decision maker knows what the possible outcomes would be, but does not know the probabilities associated with each outcome; guessing which of the outcomes will actually take place is a more specious endeavor. (c) The decision maker has an incomplete knowledge of the possible outcomes, and hence the probabilities associated with any of the known options are speculative. (d) The decision maker has incorrectly identified the problem, and as a result identified all the wrong options; the probabilities associated with any of the incorrect options thus become meaningless if they were known.

In light of the potential complexity of situations, probabilities, and alternatives that face decision makers, it would be valuable to have decision aids that would identify scenarios, probabilities, and make related calculations. Decision aids may take the form of singular simple equations, such as a multiple linear regression equation, or a complex computer program such as some of the expert systems that currently exist. It is here that the linkage between complexity theory and the control of uncertainty dates back to the late 1940s. The landmark contributions are chronicled here in three epochs: artificial life and artificial intelligence, control of chaos from the mathematical point of view, and control of dynamical events from the point of view of social processes.

2. Artificial Life and Artificial Intelligence

Although John von Neumann is perhaps best known for the theory and development of electronic computers, he also created a vision for software that became known as "artificial life." The central premise was that all life could be expressed (reduced to) the processing of information. Artificial life unfolded in a series of important and complex steps over the subsequent fifty years. The following sections thus pertain to game theory, expert systems, and evolutionary programming.

2.1. Game theory

Game theory is the 1953 joint product of John von Neumann and economist Oscar Morgenstern. It offers many possible models to describe strategic, utility-driven interactions between two or more players or negotiating parties. Two opposing decision makers have a series of action options, and the utility of each action option depends on which option the opponent chooses. Joint utilities may favor strictly competitive behavior, cooperative behavior, or mixed motive (choices between competitive and cooperative) options.

In a strictly competitive game, a gain for one player is a loss for another player. Thus strategic decision makers seek to maximize their own gains and minimize gains for their opponents; this is the minimax principle. Depending on the array of options facing each player and the utilities associated with each option, there may be a saddle point (also known as a Nash equilibrium) in the game, which would be a combination of game actions that the two opposing players would take. The existence of a saddle point implies that the outcome of a game is perfectly determined. Perfect determinism can occur if one player has full knowledge of the utilities and options facing the opponent. The theory behind the strictly competitive games has become a valuable decision aid in interpreting historic military decisions.

Prisoner's Dilemma is a mixed motive game that captured a great deal of attention as an explanation of virtually all phenomena that involve a conflict between cooperation and competition. In the Prisoner's Dilemma the players have the option of acting in cooperation with their partners, in which case both partners receive the same desirable payoff. Players' alternative option is to defect on their partner to receive greater personal payoff at their partner's expense; this is the competitive outcome.

Strictly cooperative games involve outcomes that benefit all players if all, or enough, players select the correct action option. In many such games the correct actions need to be enacted simultaneously, in which case the game can be referred to as a coordination game. In Stag Hunt, players (hunters) must exert enough effort while working together to capture the prey. Stag Hunt would explain the social loafing phenomenon in human work groups. Loafing (or free rider behavior) occurs when a group shares a reward, but only a portion of the members are working toward the reward. The reward is attained so long as enough group members do enough work.

In Intersection, the players are vehicle drivers who are approaching a four-way stop intersection. Their task is to figure out what is the rule by which the vehicles are taking turns going through the intersection, and then go through the intersection at the correct time. The Intersection game has been studied as a general model for human work group coordination and the performance of collectives.

Bandwagon is a strictly cooperative game in which the costs of engaging in a behavior or strategy decrease to the extent that more people have already chosen that strategy. One application was an explanation for the aggregation of the large crowd of people whose protest ultimately resulted in the demolition of the Berlin Wall in 1989. It became less costly to join the protest as the existing crowd became larger. Another application of the bandwagon involved inverse utilities: It became more attractive to join large discussion groups on the Internet if there were larger numbers of people generating useful information.

The mechanisms behind economic decisions have a counterpart in evolutionary biology, according to the work of John Maynard Smith. Evolutionarily stable states occur when a game is played repeatedly by a pool of potential players. Often these iterated games are simulated on a computer program. Iterated games produce long-run proportions of cooperative and competitive responses. These evolutionarily stable states are related to, but not guaranteed to be equal to, the Nash equilibria.

Iterated gaming venues eventually produce oligarchic control strategies, according to the work of Robert Axelrod. Specifically, rates of defection in a Prisoners' Dilemma are substantially attenuated if the (computer simulated) players adopt a tit-for-tat strategy in which cooperation and defection from players is a predictable result from a player's prior use of cooperation or defection strategies. In other forms of oligarchic control, players may select cooperative behavior over defection, in spite of utilities to the contrary, if they are trying to protect a reputation.

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Biographical Sketch

Stephen J. Guastello is Professor of Psychology at Marquette University, and specializes in industrial-organizational psychology and human factors engineering He is the author of *Chaos, catastrophe, and human affairs: Applications of nonlinear dynamics to work,* (1995, Lawrence Erlbaum Associates), *Managing Emergent Phenomena: Nonlinear dynamics in work organizations.* (2002, Lawrence Erlbaum Associates), and Human Factors Engineering and Ergonomics: A systems approach (2006, Lawrence Erlbaum Associates), and over 90 journal articles and book chapters Dr. Guastello is also the editor-in-chief of the journal *Nonlinear Dynamics, Psychology, and Life Sciences***.** He has served as a consultant to numerous organizations providing expertise in the areas of personnel selection and retention, occupational accident analysis and prevention, and management development.