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This is the final report of Contract N000014-86-K-0322. The mission of this contract was to develop and test a theory of collective induction, the cooperative search for descriptive, predictive, and explanatory generalizations, rules, and principles. The report consists of five parts: (1) a general theory of group problem solving and decision making in the form of four postulates; (2) competitive tests of the predictions of 20 a priori social combination models for 200 four-person groups on a rule induction task; (3) an a posteriori theory of collective induction in the form of three further postulates to account for the social combination processes of these 200 groups; (4) competitive tests of the predictions of these three postulates as a 21st a priori social combination model for 200 further four-person groups; (5) consideration of the generality of the theory.

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Subject: Final report of work completed under the support of Contract N000014-86-K-0322, Work Unit 4423003, between the University of Illinois at Urbana-Champaign and the Perceptual Science Program, Office of Naval Research.

I. This constitutes a final report of work completed under the support of Contract N000014-86-K-0322, Work Unit 4423003, between the University of Illinois at Urbana-Champaign and the Perceptual Science Program, Office of Naval Research. The contract was initiated 1 June, 1986, and was terminated 31 May, 1989.

II. SUMMARY OF RESEARCH PROGRAM

Collective induction is the cooperative search for descriptive, predictive, and explanatory generalizations, rules, and principles. The primary purpose of this research program was to develop and test a theory of collective induction. The resulting theory of collective induction (Technical Report #6, 3 July, 1989, which supersedes Technical Report #5, 23 January, 1988) consists of five parts. The *first part* reviews the social combination approach and proposes a general theory of group problem solving and decision making in the form of four postulates. The second part competitively tests the predictions of 20 a priori social combination models for 200 four-person groups on a rule induction task. The third part proposes an a posteriori theory of collective induction in the form of three further postulates to account for the social combination processes of these 200 groups. The fourth part competitively tests the predictions of these three postulates as a 21st a priori social combination model for 200 further four-person groups. The fifth part considers the generality of the theory.

1. A General Theory of Group Problem Solving and Decision Making

Postulate 1: Group problem solving and decision making is a social combination process that maps a distribution of individual group member preferences onto a single collective group response.

Postulate 2: Group problem solving and decision making may be ordered on a continuum anchored by intellective and judgmental tasks. Intellective tasks are problems or decisions for which there exists a demonstrably correct solution within a verbal or quantitive conceptual system. The objective for the group is to achieve the correct solution, and the criterion of group success is whether or not the solution is achieved. Judgmental tasks are evaluative, behavioral, or aesthetic judgments for which a demonstrably correct response does not exist. The objective for the group is to achieve consensus, and the criterion of group success is whether or not consensus is achieved.

Postulate 3: A demonstrably correct group response requires four conditions:

Postulate 3a: There must be group consensus on a verbal or quantitative conceptual system.

Postulate 3b: There must be sufficient information for solution within the system.

Postulate 3c: The group members who are not themselves able to achieve the correct response must have sufficient knowledge of the system to recognize and accept a correct response if it is proposed by other group members.

Postulate 3d: The correct members must have sufficient ability, motivation, and time to demonstrate the correct response to the incorrect members.

Postulate 4: The number of group members that is necessary and sufficient for a group response is inversely proportional to the demonstrability of the response.

2. Twenty A Priori Social Combination Models of Collective Induction

A rule induction task was designed to abstract the two essential aspects of hypothesis formation and hypothesis evaluation in collective induction. The task required the induction of a rule that partitioned a deck of 52 standard playing cards with four suits (clubs, diamonds, hearts, and spades) of 13 cards (ace, ..., king) into examples and nonexamples of the rule. Aces were assigned the numerical value of 1, deuces 2, ..., jacks 11, queens 12, kings 13. Instructions stated that the rule could be based on suit (e.g., "diamonds"), number (e.g., "eights"), or any combination of operations on suit and number (e.g., "diamond or spade eights," "even diamonds or odd spades," or "diamonds and spades alternate"). The problems began with a card that was known to be an example of the rule face up on a table (e.g., the eight of diamonds for the rule "two diamonds and two spades alternate"). On each trial each of four group members first wrote a hypothesis on their individual hypothesis sheet. The group then discussed to consensus on a single group hypothesis, which one randomly selected group member recorded on a group hypothesis sheet. The group then played any of the 52 cards. If the card was an example of the rule it was placed face up to the right of the known example, and if the card was a nonexample of the rule it was placed below the known example. Each member then made a second hypothesis, followed by a second group hypothesis and a second card play. This procedure continued for a series of trials, followed by the final member hypotheses and group hypothesis. There was no feedback on the hypotheses until after the final group hypothesis.

How does this rule induction task relate to Postulates 1, 2, 3, and 4? All proposed hypotheses are either plausible or nonplausible. Plausible hypotheses are consistent with the entire array of examples and/or nonexamples, whereas nonplausible hypotheses are inconsistent with at least one example or nonexample (e.g., the hypothesis "diamonds" when a diamond has been a nonexample or a spade has been an example). One of the plausible hypotheses is designated as correct. The group members begin the task with consensus on the basic verbal and mathematical systems, including the meaning of concepts (e.g., suit, number, diamonds, ace, 1), the mapping of cards onto numerical values, (e.g., ace = 1), and the meaning of numerical and logical operations (e.g., addition, greater than, alternation), thus fulfilling Postulate 3a. There is always sufficient information in the array of example and nonexample cards to demonstrate the plausibility or nonplausibility of a proposed hypothesis. However, there is never sufficient information to demonstrate that a given plausible hypothesis (including the single correct plausible hypothesis) is uniquely correct relative to some other plausible hypothesis. Thus, the rule induction task is near the intellective end of the task continuum and fulfills Postulate 3b for plausible hypotheses (including the single correct hypothesis) relative to nonplausible hypotheses. In contrast, the task is near the judgmental end of the continuum and does not fulfill Postulate 3b for plausible hypotheses (including the single correct hypothesis) relative to other plausible hypotheses, or for nonplausible hypotheses relative to other nonplausible hypotheses. The group members should have sufficient knowledge of the system to accept a demonstration that a proposed plausible hypothesis is plausible or a proposed nonplausible hypothesis is nonplausible, thus fulfilling Postulate 3c. Fulfillment of Postulate 3d depends upon the ability and motivation of the group members, the difficulty of the correct rule, and the available time.

On each trial one or more group members may propose the correct hypothesis, a given plausible (but not correct) hypothesis, or a given nonplausible hypothesis. Using subscripts to denote the number of members who propose the correct hypothesis (C_n), a given plausible hypothesis (P_n), and a given nonplausible hypothesis (N_n), there are 38 possible distributions of member preferences on each trial in four-person groups: C_4, C_3P_1, C_3N_1, ... , $N_1N_1N_1N_1$. The group hypothesis may be C, P_4, P_3, P_2, P_1, P_0 (a plausible group hypothesis not proposed by any member on that trial), N_4, N_3, N_2, N_1, or N_0 (a nonplausible group hypothesis not proposed by any member on that trial). Any social combination theory of collective induction predicts the conditional probabilities of each possible group hypothesis for each of these 38 distributions of member hypotheses.

Previous research on social combination models on different types of group tasks has found support for five basic processes: (1) proportionality: the group response is proportional to the number of members who advocate a given response; (2) equiprobability: the group response is equiprobable among responses advocated by at least one member; (3) majority: the group response is that advocated by a majority (typically two thirds) of the group members; (4) truth-wins: a single correct member is necessary and sufficient for a correct group response; (5) truth-supported wins: two correct members are necessary and sufficient for a correct group response. These generate 20 a priori social combination models, such as Proportionality, or Majority, Proportionality (a proportionality subscheme when there is no majority).

The review of research and discussion of the rule induction task predicts that the best-fitting of these 20 a priori models will be Truth-supported Wins, Majority, Proportionality. The groups should propose the correct hypothesis if it is proposed by at least two group members, and follow a majority process if it is not. If there is no majority they should follow a proportionality process.

Two hundred four-person groups each solved one rule induction problem. These 200 groups were from two published experiments, 128 from Laughlin & McGlynn (1986) and 72 from Laughlin (1988; Technical Report #1, revised and superseded by Technical Report #2). [The proportions of possible group hypotheses for each of the 38 distributions of member hypotheses did not differ for the two experiments, so the 200 groups were combined to increase the power of tests of goodness of fit.] As predicted, the best fitting model was Truth-supported Wins, Majority, Proportionality.

3. An A Posteriori Theory of Collective Induction

An a posteriori social combination model that provides a parsimonious summary of the data for the 200 groups may be formulated as three further social combination postulates in collective induction.

Postulate 5: If at least two members propose the same hypothesis the group selects among only those hypotheses proposed by the group members; if no two members propose the same hypothesis the group selects among the hypotheses proposed by the group members and proposes a new emergent group hypothesis with probability 1/S (where S is group size).

Postulate 6: If at least two members propose plausible and/or correct hypotheses the group selects among proposed plausible and/or correct hypotheses only; if one or no members propose a plausible or correct hypothesis the group selects among all proposed hypotheses.

Postulate 7: The distribution of group member hypotheses determines the group hypothesis:

- Postulate 7a: If all group members propose the same hypothesis the group proposes that hypothesis.
- Postulate 7b: If a majority of group members propose the same hypothesis the group follows a compromise between a majority process and a proportionality process.
- Postulate 7c: If two or more subgroups of equal size (with more than one member per subgroup) each propose a different hypothesis the group follows a proportionality process.
- Postulate 7d: If a plurality of group members propose the same hypothesis the group follows a compromise between a plurality process and a proportionality process.
- Postulate 7e: If all group members propose a different hypothesis the group follows a proportionality process and proposes a new hypothesis with probability 1/S (where S = group size).

The predictions of Postulates 5, 6, and 7 were then tested against the data for the 200 groups by the same goodness of fit procedure, fitting better than all of the 20 a priori models.

4. An A Priori Test of the Theory of Collective Induction

As an a priori test of the theory of collective induction expressed in Postulates 5, 6, and 7, another 200 four-person groups each solved one rule induction problem (Technical Report #3, 5 January, 1988; Technical Report #4, 3 August, 1988). The procedures were the same as those for the first two hundred groups. As predicted, the best-fitting model was for Postulates 5, 6, and 7, which fit better than all of the other 20 a priori models.

In summary, the a posteriori social combination model formulated as Postulates 5, 6, and 7 was tested as an a priori model for 200 new groups, and had a better fit than the other 20 a priori models. This is cross validation for the theory of collective induction. Since Postulates 5, 6, and 7 assume the general social combination theory of group problem solving and decision making of Postulates 1, 2, 3, and 4, the results support both the specific theory of collective induction and the general social combination theory of group problem solving and decision making.

5. Generality of the Theory of Collective Induction

The theory of collective induction expressed in Postulates 5, 6, and 7 was tested on an abstract and controlled rule induction task with college students. Will the theory generalize to the many important task domains in which other groups, such as scientific researchers or securities analysts, seek collective inductions?

The rule induction task abstracts the essential aspects of real world collective induction. Each hypothesis corresponds to a proposed generalization or theory, and each card play corresponds to an experiment or observation designed to test predictions from the proposed generalization. The set of possible hypotheses is indeterminate rather than determinate at the outset of the problem, corresponding to the large number of initially indeterminate hypotheses in a typical real world inductive domain. The progressive array of examples and nonexamples corresponds to the progressive growth of evidence and the concomitant reduction in the number of plausible hypotheses. Thus, because of these abstractions of the essential aspects of collective induction, the theory and results should have implications beyond the specific rule induction task and groups of this research. Since Postulates 5, 6, and 7 make precise predictions, the generality of the theory may be assessed for other groups in other inductive domains.

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VI. RECOMMENDATIONS TO FUNDING AGENCIES FOR FURTHER RESEARCH

The results of this rsearch program indicate a remarkably orderly social combination process for college students on an abstract rule induction task. The process may be parsimoniously described in three postulates, which in turn assume four general postulates of a social combination theory of group problem solving and decision making. The obvious question for future research is whether the same orderly and theoretically parsimonious social combination processes apply for the many groups, such as scientific research teams, intelligence analysts, weather forecasters, or air crash investigators, who seek collective inductions in other task domains.

Groups externalize the internal cognitive processes of individuals. For example, the results showed that groups with a majority who favor one hypothesis and a minority who favors another follow a compromise between a majority process and a proportionality process. Individuals may follow a comparable compromise process when the majority of the evidence leads to one induction but a minority of the evidence leads to another. This could be tested by having individuals propose multiple hypotheses on each trial and evaluate them on multiple arrays. Thus, research on collective induction may provide theoretical insights to guide further research on individual induction.

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