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Discovery and Problem Solving: Triangulation as a Weak Heuristic

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Abstract

Recently the artificial intelligence community has turned its attention to the process of discovery and found that the history of science is a fertile source for what Darden has called 'compiled hindsight.' Such hindsight generates weak heuristics for discovery that do not guarantee that discoveries will be made but do have proven worth in leading to discoveries. Triangulation is one such heuristic that is grounded in historical hindsight. I will explore this heuristic within the general framework of the BACON, GLAUBER, STAHL, DALTON and SUTTON programs. In triangulation different bases of information are compared in an effort to identify gaps between the bases. Thus, assuming that the bases of information are relevantly related, the gaps that are identified should be good locations for discovery and robust hypotheses.

Introduction

Part of the fascination of the history of science rests in the accounts of scientific discovery. The exuberant, triumphant stories of scientific discovery give shape to our vision of scientific inquiry and substance to the high status we accord it. However, as one begins to think about, analyze and conceptualize the process of scientific inquiry, clouds of suspicion gather. The triumphant stories are often stories of insight, imagination, luck or other characteristics that seem opposed to the idea that scientific inquiry is orderly, methodic and logical. Are scientific discoveries works of genius unfettered by the dictates of logic and the constraints of empirical research? Are scientific discoveries the results of good fortune and not careful methodic analysis? If so — if discovery requires genius or good fortune — and if one holds that scientific research is the paradigm of methodic, critical, logical reasoning, then it appears that discovery is not really a part of scientific research at all and is certainly not it most distinguishing feature.

The tensions and oppositions of the foregoing considerations can lead to a strict separation of the contexts of discovery and justification. Quickly put, the distinction is a distinction between processes that give rise to new ideas and theories and processes that test proposed ideas and theories. Since it is only in testing ideas and theories that the dictates of logic and the rules of empirical adequacy are appropriate, it is justification, and not discovery, that is the hallmark of scientific inquiry.

If one accepts that the hallmark of scientific inquiry is its base in logic and standards of empirical adequacy, then if one wishes to claim that scientific discovery is equally a part of and characteristic of that sort of inquiry, then it must be made clear that it is possible for there to be a logic of discovery and attempt to produce that logic.

Heuristics and the process of discovery

Heuristics are procedures that generate desired results some of the time. Unlike algorithms, heuristics do not guarantee that a correct result will be produced in finite time and space. More precisely, an algorithm is a procedure composed of a finite, stepwise sequence of instructions such that (1) given the initially required information the procedure will be completed in finite space and time, (2) no additional information or creativity is required to carry out the instructions, and (3) the result of the procedure is a correct result. This definition is clearly normative owing to condition 3. This condition is added to prohibit consideration of trivially algorithmic procedures. Heuristics differ from algorithms in that the three condition do not apply in a categorical manner. Although heuristics may often terminate with correct results in finite time and space using only specified information, they need not always do so. The strength of a heuristic is a function of its previous success and the conditions under which it is used. Heuristics embody *compiled hindsight* [1]. A heuristic is a strong heuristic when it has been highly successful in the past and is being applied under appropriate conditions.

Discovery is a process that consists of generation and evaluation [4]. In generation new ideas, hypotheses or theories are articulated or constructed. In evaluation these hypotheses, ideas or theories are tested for plausibility. Intuitively, plausibility differs from justification in that theses judged plausible need not be justified but all justified theses must be plausible. The judgments of novelty in generation and plausibility in evaluation are context dependent. For a certain body of information a thesis may be novel and plausible, while for a different body of information it may fail to be either. Understanding discovery as a process combining generation and evaluation allows one to interpret scientific inquiry as movement from the novel and plausible to the routine and justified.

If the notions of 'logic' and 'discovery' are understood to encompass heuristics as well as algorithms and processes of generation and evaluation as well as moments of insight, then it seems reasonable to believe that there are logics of discovery. The reasonableness of this belief does not entail that there is some unique logic of discovery. Rather it allows that there may be several.

The artificial intelligence community has generated several programs that embody logics of discovery. Langley et al. [3] have examined four particular families of programs: BACON, GLAUBER, STAHL and DALTON. The BACON programs can be understood as generating plausible quantitative laws. By generating a complete experimental combination of the values of dependent and independent variables, and by attempting to extract constants and mathematical relations, the program searches both the space of data and the space of laws in an effort to find laws that accurately summarize the data. The primary heuristics of the BACON programs concern the identification of constants and linear relations. The GLAUBER program can be understood as generating qualitative laws that relate classes of facts. Its primary heuristics concern the formation of classes that best summarize the relations between the predicates, attributes and values of the data and specify the quantifiers (universal or particular) that generate law-like claims. The STAHL program attempts to specify the components of a compound by examining facts about reactions and the substances present in them. The primary heuristics of this program concern reduction, substitution and the identification of components and compounds as being the same. The DALTON program begins with data concerning reactions and the components of compounds and attempts to formulate a model that explains the reaction. Its primary heuristics concern the number of occurrences of atoms and compounds and principles of conservation across reactions. Darden and Rada [2] have devised the SUTTON program to capture the discovery of the chromosome theory of heredity. Its primary heuristics concern part-whole relations, identity and causal propagation.

Discovery programs that concern scientific reasoning clearly profit from the compiled hindsight that can be extracted from the history of science. Procedures that have proved valuable in the past can be converted into heuristics that may be of value in the present. Each of the foregoing discovery programs embodies procedures abstracted from the history of science which are reformulated in terms of the such well understood strategies as 'generate and test,' 'hill climbing' and 'means-ends analysis.'

Triangulation

The heuristics used in discovery programs are neither sufficiently general to be used in all cases nor sufficiently mechanical to guarantee results. Discovery heuristics are context sensitive; their strength varies according to the context. Another heuristic that can be extracted from the history of science turns these difficulties into virtues. *Triangulation* allows for the the comparison and evaluation of different bases of information with the goal of generating more coherent and robust accounts of those bases. [5,6,7].

The heuristic of triangulation can be formulated as a group of related rules concerning generation and evaluation.

1) *If* there is a pattern in domain A that closely matches a pattern in domain B and the pattern of domain B is plausible,
then use the structure of the pattern in B to generate new patterns in A.
2) *If* the domain A does not have a clearly defined pattern and there is some domain B that contains concepts that closely match those in A,
then use the structure of the pattern in B to generate new patterns in A.
3) *If* a result in domain A is generated in accord with 1 or 2, and the result closely matches a result in domain B,
then accept the result as plausible.
4) *If* the plausible results of A closely match the plausible results of B in both structure and concepts,
then unify the domains and evaluate all of the patterns of A and B in the new domain.
5) *If* plausible results are generated in a domain formed in accord with 4,
then attempt to justify the results.
6) *If* there are patterns that do not hold for domains formed in accord with 4,
then identify the conditions under which the patterns do not hold, make these conditions the antecedents of material conditionals and evaluate.

Triangulation is clearly a weak heuristic. There is no guarantee that the process will be successful in entering into the context of justification. Triangulation can generate implausible results and it can generate results that may be erroneous. However, triangulation makes good use of the results of other heuristics used in differing contexts, and attempts to bridge the gaps that could be created by applying other heuristics in a particular domain without considering the results in other domains. It does so by generating hypotheses in accord with both structural and conceptual analogies (rules 1, 2 and 3) derived from other contexts. Further, triangulation amplifies the coherence of results by generating a unified domain and generating new conditionalized hypotheses (rules 4, 5 and 6). The hypotheses generated in this manner serve to address two criteria of plausibility not directly addressed by other heuristics. First scientific hypotheses are often deemed plausible on the basis of analogies to patterns in other more well understood domains. Second scientific hypotheses often gain plausibility by unifying domains even when the unification generates patterns that are more restrictive.

The heuristic of triangulation can be extended to provide a gateway to reasonings that are even more extensible. In the foregoing rules only the relation of unification has been considered. Other relations are possible. Two domains may retain their autonomy and still be relevantly related. Neighboring domains may force constraints on what is to be considered a plausible hypothesis in a particular domain, or a new plausible and justified result in a particular domain may force alteration in the plausible patterns of other domains. By extending the heuristic of triangulation to include such a gateway, discovery processes that are neither data driven nor theory driven may be investigated.

Conclusion

It is reasonable to consider the context of discovery to be amenable to rational analysis provided that the notion of logic is extended to include heuristics and the notion of discovery is extended to include processes of generation and evaluation. These extensions allow for the possibility of a logic of discovery, but do not demonstrate that there is such. One way in which it can be demonstrated that there is a logic of discovery is by constructing programs that generate discoveries. Such programs have been constructed. However, the heuristics of these programs focus primarily upon the data in a single domain. The heuristic of triangulation uses the patterns and results of one domain to generate and evaluate the results of another domain. This heuristic focuses on the scientific values of analogical support and increased coherence, and makes possible a gateway to other forms of extensible reasoning. Thus, triangulation should prove to be a valuable addition to the treasury of heuristics of discovery.

References

[1] Darden, Lindley. "Viewing the history of science as compiled hindsight," *Institute for Advanced Computer Studies (University of Maryland)*, UMIACS-TR-86-20/CS-TR-1715. Forthcoming in AI Magazine.

[2] Darden, Lindley and Roy Rada. "Hypothesis formation using part-whole interrelations," *Institute for Advanced Computer Studies (University of Maryland)*, UMIACS-TR-87-17/CS-TR-1832

[3] Langley, Pat, Herbert Simon, Gary Bradshaw and Jan Zytkow, *Scientific Discovery: Computational Explorations of the Creative Processes*, Cambridge, Mass.: The MIT Press, 1987.

[4] Schafffner, Kenneth. "Discovery in the biomedical sciences: logic or irrational intuition" in *Scientific Discovery: Case Studies*, Thomas Nickles (ed.), Boston: D. Reidel, 1980, pp.171-206.

[5] Rochowiak, Daniel. "Darwin's psychological theorizing: triangulating on habit," *Studies in History and Philosophy of Science*, forthcoming.

[6] Rochowiak, Daniel. "Extensibility and completeness: an essay on scientific reasoning," under review.

[7] Rochowiak, Daniel. "Expertise and reasoning with possibility," NASA Artificial Intelligence Conference, November 1986.