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IN SEARCH OF EXPLANATIONS: FROM WHY-QUESTIONS TO SHAKESPEAREAN QUESTIONS*

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ABSTRACT
The paper develops a notion of scientific explanation based on Jaakko Hintikka's interrogative model of inquiry. Explanations are interrogative derivations of an explanandum from initial premises and answers given by nature. This I-model explains where the covering law idea went wrong, how the process of explanation can be dealt with, and why strategies are important: in explanation genuinely new information can and must be obtained all the time. The paper argues that despite difficulties the logic of questions can be extended to explanation-seeking why-questions.

1. *The Logic and Pragmatics of Explanation*

The notion of an explanation has suffered from the process/product ambiguity. Practically all of its explications, from the long-reigning covering law model of Hempel and Oppenheim (H-O, for future reference) to its latter day rival, Salmon's statistical relevance model (S-R), have focused on the latter aspect. From the product perspective the historical contingencies which lead to any given explanation are irrelevant; the explanatory relationship is either a deductive (or inductive) one between sentences, or a display of properties relevant for the occurrence

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of an explanandum event.

One notable deviation from the product-centred mainstream is the pragmatic explaining-act-centred notion of Peter Achinstein (1983). I have previously argued along similar lines that formal models of explanation are bound to fail, and that we can see where and why they fail by considering certain pragmatic features of question-answer sequences (Sintonen 1984 and 1989). The argument was that the notion of scientific explanation inherits the conversational structure of acts of explaining, and that the many proposals, such as H-O, have in vain attempted to capture pragmatic features of discourse by purely syntactic and semantic means. In pragmatic models of explanation there is room not just for sentences or statistically relevant properties, but also for explainers and explainees, questions and answers, paradigms and contexts, and you name it.

I still consider pragmatic notions of explanation a healthy antidote to overly simplified formal notions, mainly because they force us to keep in mind that question-answer games take place in a wider social setting. But on balance, I think that behind both H-O and S-R there was the sound and laudable aim of finding an objective notion of explanation. If pragmatic models of explanation are on the right track, and if explanations can be explicated as answers given by one member of a scientific community to another, the notion of a scientific explanation is either rendered trivial, or else its ties to the hard world are severed. To put this worry succinctly, if scientific explanation is exclusively a matter of what goes between me and my pals, it is too easy.

The trouble is that although pragmatic questions-to-fellow-inquirers-notions take into account some conversational features of question-answer-sequences, they do not allow for a dialogue with nature. And whatever might be thought about the pitfalls of the questions-to-nature idea, it is clear that in the end explanations must come to terms with the world out there (See Sintonen 1990). The dilemma seems to be that between logic and pragmatics: the logical accounts confine to static accounts of end-products within interpreted formal languages, whereas the pragmatic ones focus on acts of explaining and thereby mirror some important features of explanation. Yet they fail, too, because they keep the inquirer and nature too far apart.

However, things are not quite as bad as this, for the interrogative idea of inquiry can be developed in a direction slightly different from the direction of pragmatic models. This interrogative model (I-model) developed especially by Jaakko Hintikka, takes seriously the idea of putting questions to nature. Furthermore, there is a well-behaved but flexible enough underlying logic in the model, so that it is able to accommodate also some of the insights achieved within pragmatic models of explanation.

I shall start by outlining the nascent interrogative model of explanation (section 2), and then argue that it is able to illustrate the process of explanation (section 3). Section 4 is devoted to the notion of an interrogative derivation, a key notion in the logic of the model, and section 5 explains what went wrong with the covering law paradigm. Section 6 deals with the logic of questions and answers, and sections 7 and 8 argue that although the weak logic of why-questions poses some extra difficulties, the I-model of inquiry helps us make some progress towards understanding them, too.

2. *The I-Model of Inquiry*

The idea that inquiry is a process of queries and answers is an age-old metatheoretic insight, and one may wonder why the process aspect has remained dormant so long. Why, despite the opening sentences of Hempel and Oppenheim (1948), was the idea not put to better systematic use? One reason for this lack of progress was no doubt the lack of adequate logical tools at that time. Neither erotetic nor epistemic logic were at hand, so that the intuitively appealing *way of questions* must have appeared formally intractable. With scant tools to deal with growth of explanatory (or any other) knowledge, that aspect of inquiry was to be bracketed. The alternative was to think that what counts as an acceptable answer is a thoroughly anthropomorphic affair. And this comes very close to the thought that, as Michael Scriven (1975, p. 4) later put it, the notion of explanation owes its meaning to subjective and straightforwardly psychological factors, that is, factors which the covering law paradigm was designed to rule out.

There is also a third, related worry about the way of questions and answers. Several people have maintained that although the intuitive idea is attractive, it is too messy to serve as a core notion in an account of scientific explanation. Furthermore, since many (if not all) explanation-requiring questions are why-questions, there is the special worry explicating why-questions. And this explication, the critics say, was not available then, nor is it available now. I shall deal with the special difficulty of why-questions in section 6, and here only address the general concern over the method of questions.

The standard source of sceptical worry is that the process of explanation involves discovery and innovation, and since there simply can be no logical way of having ideas, there can be no logic of discovery. Discovery is considered arational if not irrational. Now several writers on the topic feels sympathy for the interrogative idea, but although they consider it heuristically useful they fail to discern any logic. Thus Gary Gutting (1980, p. 38) writes that discovery always starts with a question, and that it is guided by "empirical, theoretical, and methodological givens" of the question-context. He then notes the availability of previously obtained facts "relevant to the description and explanation of the empirical facts" and "methodological strategies for developing an answer to the questions". These strategies include heuristic tricks, mathematical and experimental techniques, as well as directives "derived from very general assumptions about the world and of scientific inquiry." But however useful these tricks, techniques and directives are, they comprise, Gutting thinks, a motley crew, a far cry from logic.

But of course there is now a logic of questions and answers, as proposed originally by Jaakko Hintikka. Let me first quickly sketch this I-model of knowledge-seeking at large, for it serves as the background for the nascent model of explanation. In this model knowledge-seeking is looked upon as a *game* against Nature where an Inquirer sets out to derive a suitable cognitive objective by subjecting Nature to an array of questions, and by trying to derive this objective from Her answers and from the Inquirer's own background knowledge.

The general characterisation allows for different more specific models, depending on who the fellow locutor is (e.g., it need not be Nature but can also be the Inquirer's dormant subconsciousness, a database, a fellow investigator, or in general any source of knowledge). It also depends on the types of answers allowed. The extremes are games in which all answers confine to atomic propositions and their negations, and games in which formulas of any given quantificational complexity are allowed. As Hintikka (1985) has demonstrated, there is a continuum of mediating types of inquiry, with the following property: the richer the background theory is, the simpler can be the questions. The guise of the model also depends on the task. The task can be to prove a well-defined proposition, as when a theory is tested through its interrogative import, or when a theory's explanatory power is explored, or the task can be the finding of a theory which answers certain demands. Roughly, explanatory tasks fall in the latter category, although during the search of an explanation smaller proof-tasks are interspersed.

However, all submodels share the crucial feature that the steps in the knowledge-seeking process can be divided into two general kinds, deductive and interrogative moves.[1] Deductive moves are what the title promises, namely, deductions from the premises the inquirer already possesses. Interrogative moves are steps in which new information is brought into the derivation. All moves in which new information is brought in can be considered as answers to questions, whether or not the inquirer actually ever aired the questions or heard the answers, and whether or not she or he is aware of ever witnessing such linguistic or mental episodes. In this sense, not only premeditated experiments but also uninvited observations which feed in information can be construed as answers to questions put to nature.

A process of querying and answering can be codified in terms of the semantical tableaux employed by Beth and Hintikka, with explicit tableau-construction rules governing deductive moves, and further rules governing admissible interrogative moves. Again, the basic setting allows for variation, but as a rule there is no moving of items from the right hand column to the left hand one in a tableau. It is also assumed that before an inquirer can raise a question, the presupposition of that question must occur in the left column. An important idea is the requirement that any given game is tied to a particular model M and its language, usually first-order language, so that nature's answers are presumed to be true in the model M. In the simple game in which the aim is to prove a predetermined conclusion, the inquirer has succeeded when she or he has closed the tableau. What the inquirer attempts to do, then, is to prove the conclusion by forcing nature to give unambiguous answers to her or his questions, answers which the inquirer then can avail in the interrogative derivation of the chosen conclusion.

3. *Explanation and Strategic Thinking*

I have argued elsewhere (Sintonen 1993) that the I-model gives new hope for, and badly needed tools to, the friends of discovery, for it is able to throw light on how new theories are discovered. But of course discovery overlaps, in part, the theory of explanation, when viewed from the process perspective. More specifically, applied to the notion of explanation the model has it that explanation is a process in which an inquirer I who knows that E but does not know why E tries to find suitable pieces of information $A_1, \ldots, A_i$ which, together with I's background knowledge T, entail E. In the tableau construction this process is codified as follows. The inquirer's background knowledge, including the relevant theory T, is entered on the left hand column, and the explanandum E on the right hand column. By help of the interrogative moves the inquirer obtains whatever auxiliary singular facts and generalizations $A_1, \ldots, A_i$ are needed to close the tableau. Now closing the tableau shows T and $A_1, \ldots, A_i$ entail E, a feat which parallels deductive entailment in the D-N -model of explanation.

It follows from this, of course, that interrogative derivability cannot be the whole story about explanation (or all explanations), for it cannot weed out *all* non-explanatory derivations. Thus the I-model inherits some of the problems of the D-N model, such as the notorious problem of asymmetry (see Salmon 1989). However, as will become evident in section 5, since the I-model looks upon the search for an explanation as knowledge acquisition, it avoids the many other problems which proved to be fatal for the D-N model, such as the various types of self-explanations, and of irrelevant pieces of information.

In explanations the explanandum phenomenon can be a singular fact, a generalisation or law, and depending on what the inquirer already knows, the search for an explanation can amount to a search for a general theory or law of the target phenomenon, or for singular facts needed for the interrogative derivation to go through. And as will become clear in section 6 below, this duality of explanatory tasks can be given an elegant formulation in terms of conclusive answerhood. For the items which are needed for an explanatory task but which are contextually obvious (part of the background knowledge left unspecified for pragmatic reasons) enter into explanations as conditions for the answers to be conclusive.

Thus stated the I-model of explanation bears some resemblance to the covering law paradigm, and especially to Hempel's deductive-nomological model of explanation — in fact it continues the interrogative task of Hempel and Oppenheim, albeit by improved tools. However, this interrogative construal has several features which make it particularly suitable for the description of actual research processes, and not just finished research reports. It awakens the question-answer-perspective left dormant in H-O, without succumbing to brute pragmatics. Yet it does justice to dynamic features of knowledge acquisition. It also forces us to reassess the claim that search for explanatory theories is beyond the purvey of logic. Let me briefly expand on these.

Note, first, that the model is in full accordance with working scientists' self-understanding, for any well-structured research project can be cast in the form of an interrogative portrayal which starts from some big initial questions and then proceeds to answer them by help of small operational questions. This duality is vital to the understanding of empirical inquiry: there are the big initial questions which circumscribe the goal, and smaller questions which establish auxiliaries and hence contribute towards achieving the goal.

Secondly, the model literally construes the search for explanations as a question-answer *process,* bringing in a much needed dynamic aspect to metatheory. The demand for dynamics is not novel, but the specific response of the I-model is. As already noted the model insists that auxiliary singular (and general) facts about a given model M (the actual world) can and must be established during interrogative derivation. This feature of the model backs up the intuition of practising scientists that explanatory theories are not born in full attire, sufficient to deal with all applications to come. Rather, fundamental but nascent insights must be nurtured until they turn into powerful theories. Furthermore, this nurturing involves an interrogative dialogue (or monologue) of questions that cannot be anticipated when the fundamental insights first occur.

Third, the idea that inquiry is a game, coupled with the idea that not all information need (or can) be at hand when a search is commenced suggests that *strategic* aspects of question-answer sequences are vital in carrying out research. Again the model refines an idea familiar to all scholars and scientists, namely, that asking a good question at the right time serves the long-range purposes of maximising knowledge output better than a myriad of aimless deductions. And what the interrogative model adds to this is a systematic study of the strategic aspects of raising and answering questions. There are characteristically several ways to reach a conclusion, and one important scientific skill is that of organising one's questions in a cost-efficient way. All experimental set-ups and all systematic observations require planning and hence answers to questions such as this: Suppose we do find out, on the basis of this or that observation or experiment, that p. How is this piece of information going to help us answer the initial questions?

Fourth, the I-model makes it possible for us to take new look at discovery. The standard objection to discovery programs has been that the generation of new ideas and specific hypotheses is ultimately a matter of guess and luck, and that there simply can be no logical way of having ideas. The received view has it that such issues belong to the psychology of creative thinking and, perhaps, history of science, but at any rate not to the logic and methodology of science.

Here the model joins the friends of discovery in the appraisal that the discovery process is too important to leave to psychologists and historians. Working scientists have often stressed the difficulty of dividing the process of inquiry into distinct stages of discovery and justification. The interrogative model can alleviate their *Angst* because its basic logic makes natural allowance for justificatory moves in the midst the pursuit of a full-fledged theory, or even during the generation of a basic idea. In an important sense, then, the model abandons the discovery/justification bifurcation of recent decades, and vindicates the (historically speaking) traditional view that there is no separate stage of justification to be appended to an otherwise complete success story of discovery.

4. *Interrogative Derivability*

With these remarks in mind, let us have a closer look at the rise and fall of the covering law paradigm. To begin, note that the leading intuition behind H-O and the subsequent deductive-nomological-model (D-N) was that explanations are inferences or arguments, in which the conclusion E is deductively entailed by the premises. The model clearly satisfies some of the intuitive criteria of adequacy which Hempel and Oppenheim imposed, and it appears to live up to the basic rationale of this variety of epistemic models: the explanans sentences make the explanandum phenomenon (nomically) expected, for here the explanatory relationship is one of logical entailment.

In the interrogative model the explanatory relationship is cashed out as *interrogative derivability*, with the crucial *differentia* singled out above: the inquirer is allowed, encouraged and even required to make small questions whenever she or he feels new information is needed. This rings true both logically and heuristically. In the I-model explanatory import is not assessed through the logical consequence of a theory, but rather through its model consequences. As Hintikka (1984) puts it, in model-oriented logic the inquirer uses the initial (and possibly hypothetically adopted) theory T and particular facts A_1, ..., A_n about a given model M (the actual world) to find out how things are in some yet unexplored part.

One difference between the two notions comes clear when we ask what an optimal theory is like in view of them. On the deductivist view the optimal theory is one which enables the inquirer to decide, for each proposition E in the theory's language, whether E or not-E. An optimal theory in this sense is complete. On the model-theoretic view an optimal theory is one which allows the inquirer to answer every *question* in each of the models of T. If we assume that the answers obtained from nature are all (negated or unnegated) atomic sentences this ideal amounts to a theory which satisfies the condition that for every E in the language of the theory there is a finite set of atomic propositions $A_1, A_2, \ldots, A_i$ true in M such that either $T \cup \{A_1, A_2, \ldots, A_i\} \vdash E$ or $T \cup \{A_1, A_2, \ldots, A_i\} \vdash \sim E$.

The two notions are distinct, and not all model complete theories are complete or vice versa. However, the overall heuristic import of the interrogative model is even more obvious than the said logical point. For clearly, D-N looks backward from an already embraced explanans to its conditions of acceptance, whereas the I-model looks forward from an initial but often underdeveloped theoretical premise T to a result only vaguely characterized by the desideratum of the initial question. The cognitive task set by D-N is of the form: are the (true, nomic and empirically contentful) laws T and initial conditions A sufficient for a deductive argument for E? In the I-model the task is: what information (singular facts A_1, ..., A_i *and generalizations* T_1, ..., T_n) should you try and solicit from Nature to be able to derive, on the basis of T, the explanandum E?

To appreciate the difference, we need to consider in more detail two important though tacit assumptions in D-N, imposed by the static setting.

One is that the explanans items divide neatly into two logical categories, laws and singular initial conditions, and that in singular explanation the search for explanation amounts to a specification of the latter. The other one is that all explanans items are in the same epistemological and methodological boat, in that once admitted they cannot be discarded. Both assumptions are excessively simplistic. The first one leads to a one-step picture of inquiry which is insensitive to contextually determined mediating steps in the derivation. It also misses the rather obvious fact that the items needed in the derivation of an explanation are heterogeneous in nature.

Just consider, with the former of the simplifying assumptions in mind, how far the one-step deductive ideal is from reality in one example, the theory of evolution as developed by Darwin. The theory is said to explain a host of singular facts and generalizations by the single principle of natural selection. The reigning metatheoretic paradigm has led many writers to think that Darwin's theory is deductive in structure, and empirically supported by the various classes of facts deducible from its core. But of course the theory as it was presented, or its present day descendant, was very programmatic and gappy, so much so that one can justifiably ask if the deductive ideal can be taken seriously. Nevertheless, the theory guided the work of some discerning naturalists from the start, even though, as Darwin admitted, it could not count a single detailed deductive explanation to its credit.

The standard rebuttal to this criticism can already be found in Hempel's and Oppenheim's paper. There are something that can be called complete explanations, viz., explanations which contain all premisses needed for the deduction to go through. But only premises which are not common knowledge (theories) or contextually obvious (singular facts) need be explicitly mentioned. Similarly, there are sketches, blueprints for complete explanations which need some filling in. For these reasons, writes for instance Michael Ruse, evolutionists subscribe to the hypothetico-deductive ideal, although, he admits, they "are far from having it as a realized actuality" (Ruse 1979, p. 179). Another rebuttal admits that theories alone never entail explanations and predictions, and insists that deductive theories must be provided with initial conditions. And of course, the rebuttal goes, finding the initial conditions is a separate task also in D-N.

But these admissions are not sufficiently far-reaching, for it is not just the banal requirement that extra information is needed but the very nature of this information. The laws in a D-N explanation contain slots to be filled in by *singular* initial conditions. But the important consideration, from the point of view of the I-model, is that the information needed may also contain generalisations, on different levels. The questions addressed to nature are requests not just for the values of the relevant parameters and constants, or for singular facts, but also for application-specific functional dependences.

To see this, look at, say, singular evolutionary explanations. Behind one there may loom general laws (e.g., the Hardy-Weinberg law) but these laws are highly idealised and not yet in a form into which singular initial conditions can be inserted, to produce predictions and explanations. Rather, more specific theoretical models must be designed, with model-bound assumptions of their own.[2] Patrick Suppes once proposed a hierarchy of theories which can be used to describe the way from idealised systems to actual natural systems. To visualize the hierarchy, imagine that under the grand evolutionary theory there are subtheories for various kinds of applications (for this, see e.g. Tuomi 1981), and these are again concretised to theoretical models (e.g., in island biogeography to a mathematical model for determining the equilibrium number of species on an island). However, even these are too abstract and must be further processed into experimental models concerning specific types of experiments. Finally, to get close enough to empiria there are models of data which tie experimental models to specific experimental runs. Thus, even in the process of deriving a singular explanation, the step-by-step procedure goes through the formulation of specific generalizations.

The search for explanations, then, can either be search for application-specific subtheories and equations used in models based on these theories, or it can be search for singular facts which can be plugged into low-level generalizations to yield singular (deductive or inductive) explanations. In any case the notion that the inquirer *first* formulates the laws and generalizations (the theory-component) and then starts hunting for initial conditions must go.

The other simplifying assumption is that all premises in an explanation have a secure epistemic status: once accepted, a premise cannot be withdrawn. But of course this assumption is contrary to fact, as even a cursory look at scientific work-in-progress testifies. The I-model of explanation acknowledges this fact. A successful interrogative derivation of course results in a deductive argument — after all, the tableau construction aims (with fingers crossed) at the construction of a counterexample to the claim that M: $T \cup \{A_1, A_2, ..., A_i\} \vdash E$. But the I-model contains bracketing rules and is hence open to the possibility that an assumption once made, and all results that depend on it, must be rejected. And in fact tinkering is part of the daily routine in all types of empirical inquiry. Indeed, even the most fundamental assumptions of the most fundamental theories in history, such as the second law of Newtonian dynamics, were considered open to negotiation.

Of course, the deductivist can still resort to the ultimate defence of admitting these observations but denying their relevance: the focus has been on the rational reconstruction of the results, not on descriptions of how they emerged. But this merely brings us back to square one, where the discussion about what a theory of explanation is supposed to achieve is carried out. And once we realize that the I-model gives a rational reconstruction of both the product and the process, the defence collapses completely.

5. *The Covering Law Paradigm Revisited*

Let me next briefly turn to the tortuous history of the covering law paradigm. With the benefit of hindsight, the primary virtue of H-O was that it gave this paradigm a new and admirably clear formulation by specifying what exactly would count as an admissible (deductive) covering law explanation. The series of attempts to find a solution was not unlike the series of attempts to explain the motions of planets within the confines of the standards set by Plato's Academy.

The basic intuition was, as noted, that explanations are arguments or inferences. However, since there clearly are logically valid but explanatorily worthless arguments or inferences, further restrictions had to be imposed on candidate arguments. Consider, then, the first model H-O which initiated the covering law paradigm. According to H-O a pair of sentences $\{T,C\}$ is an explanans for a (singular) sentence E if and only if (1) T is a theory, (2) C is a true singular sentence, (3) $\{T,C\} \vdash E$, and (4) there is a class K of basic sentences such that K is compatible with T, $K \vdash C$, but not $K \vdash E$ (Hempel and Oppenheim, 1948, pp. 277-278).

Here condition (4) is a syntactic restriction which bars arguments in which the singular premise C entails the explanandum E. Complete self-explanations in which C and E are identical are good examples. But what is wrong with them? They are putative explanations in which an inquirer is offered an answer which he already knows. To put this in tableau-terms, we have here a piece of a derivation in which the inquirer who knows that E receives information which is identical with E. Such moves are not just pointless but can also illustrate a general constraint on knowledge acquisition.

Notice that such derivations are automatically excluded in the I-model of explanation we are developing, for in this model the task the explainee inquirer faces is that of finding an answer to a big initial question by help of a series of small questions. The inquirer starts with some initial premises T, but when the explanandum event E occurs E is entered on the left-hand side of the tableau. Thus when the question "Why E?" is first aired its presupposition E is among the premises. Therefore, putting to Nature the questions "Is it C?", where C is identical with E, is literally question begging.

One might think that premises which already can be found on the left hand side of the tableau can be addressed to Nature — pointless though they are, they could be thought to be harmless. However, general considerations of knowledge-seeking games clearly indicate that such interrogative moves are best construed as violations of the rules of the game, and amount to what Aristotle called begging the question, that is, demanding an answer to the big initial question without the trouble of using the small questions as stepping stones (for more details, see Hintikka (1987).

The ban on *petitio principii* is generalizable, and important especially in empirical inquiry. In general, both deductive and interrogative moves must be used in the search for an explanation, and clearly many of the constraints built into H-O and its successors were motivated by precisely this intuition. Explanation has to do with the improvement of knowledge, and the sequence of questions and answers mirrors the sequence of the inquirer's epistemic states. The inquirer I may perceive some explanandum phenomenon E as problematic because it is improbable (or even impossible) given her or his background knowledge T. This means that there is a sequence of knowledge states starting from a harmonious *initial epistemic state* $K_I T$ in which I does not yet know that E. When I then learns that E but does not yet know why E, I enters an *intermediate* and essentially unstable (in fact, schizophrenic, if E and T are logically contradictory) *epistemic state* $K_IE\&K_IT$. Since believing is a cognitive and not a conative attitude, a rational but non-schizophrenic ignoramus I who perceives that the improbable (or impossible!) has materialised must admit that E and, with regrets, that he doesn't know why E. This intermediate epistemic state characteristically gives rise to a why-question, which in turn triggers the search for an answer C.

Looking at the problem of explanation with the eyes of a rational inquirer I in search of a suitable C also throws light on other events in the history of the covering law paradigm. In the end it turned impossible to give a satisfactory formulation to the many intuitive requirements — e.g., that self-evidencing explanations should be excluded, that laws and theories must be engaged essentially, and that singular premises must not be too close to the explanandum — within the static confines of the paradigm. My concern here is not with the outcome of the development, but with the question which Hempel raised as a response to one syntactic device which did steer the paradigm around one obstacle: assuming that the formal device does the job, it would be nice to know this not just as a brute fact, but as a reasoned result derived from "the rationale of scientific explanation". (Hempel 1965, p. 295).

But this is exactly what the I-model of explanation does. The many unexplanatory but logically impeccable arguments considered in the literature are not based on logical fallacies in the traditional sense, which is why they continued to pop up. But they are easy to handle within the I-model which distinguishes between the rules which govern interrogative moves and logical-inference rules. Just consider what Hempel and Oppenheim called self-evidencing explanations, arguments of the form

$$
\begin{array}{lll}
(1) & T': & (x)M[x] \\
 & C: & M[a] \supset P[a] \\
\hline
 & E: & P[a]
\end{array}
$$

According to H-O (1) is unacceptable because, if T is true (as it must, in H-O), one can only verify the singular premise C by verifying the explanandum E. But the syntactic constraints do not tell us why independent verification is so important. However, a look at the rules which govern interrogative moves is helpful, for once I has landed in the unstable $K_IE\&K_IT$ she is looking for further pieces of information C and

T' which would give grounds to believe (expect) that E, but these grounds must be independent from the inquirer's knowledge that E. If this is not the case, no questions to nature are needed, and the search for an explanation becomes a deductive exercise from the premises the inquirer already has. And this would be almost as easy as asking one's fellow inquirer. Requiring independent verification highlights an important constraint built into the rules of the game: a conclusive answer must give independent grounds to expect that E. Notice, also, that the theoretical premise T' must differ from the initial theoretical premise T: with E materialized, T characteristically is part of the problem, and cannot be the entire solution.

Similar partial explanations can also be given to some other formal constraints proposed in the literature, many of them as responses to the famous counterexamples to H-O produced by Eberle, Kaplan and Montague (1961). In one of these counterexamples it is assumed that there is a true fundamental law (x)F[x] and a true singular sentence H[a]. Now (x)F[x] implies logically another fundamental law T, given as the first premise of argument (2) below. But although (2) is logically valid and also meets the requirements of H-O, we would not say that {T,C} explains E.

(2) T: $(x)(y)(F[x] \vee (G[y] \supset H[y]))$
C: $(F[b] \vee \sim G[a]) \supset H[a]$

E: $H[a]$

But why not? The intuitive oddity about (2) is that the original law (x)F[x] and E have no predicates in common. And if (x)F[x] does not explain H[a], how could its logical consequence do that? The answer is that it doesn't, and there were a number of syntactic devices to block it. Jaegwon Kim (1963) suggested that on top of the initial four conditions we should require that no conjunct in the conjunctive normal form of C is allowed to be entailed by E. Another proposal in terms of Minimum Evidence Classes or MECs came from D.A. Thorpe (1973). A MEC for a singular sentence S is the minimum class of basic sentences which suffices to verify S. Another constraint sufficient to rule out (2), then, is the requirement that no T-consistent MEC for C can verify E.

So what is the rationale in terms of the scientific method? According to Thorpe the MEC-constraint is needed because if the theory does not mediate there would be no D-N explanation at all. T mediates between C and E when C neither entails nor is entailed by E, but what, to repeat, is the rationale? It seems that the rationale for both Kim's and Thorpe's devices is provided by the I-rules for raising questions: if C entails E, the laws have no role to play, and I has no T-independent reason to believe that E, and hence no grounds to expect that E is true *because* C is. On the other hand, where E entails the answer C or any part of it we have a complete or partial infringement of the rule banning *petitio principii*.

6. *The Rational (But Ambitious) Ignoramus*

Let me next elaborate on some further attractions of the I-model. In the logic of questions developed by Hintikka questions are construed as genuine requests for information, and they are to be classified in accordance with their presuppositions and what Hintikka calls their desiderata. The presupposition of a question is a (or the) proposition which describes the *sine qua non* of the question, the state of affairs which must hold for there to be a legitimate question at all. The desideratum in turn is a proposition which specifies the state of affairs which the questioner wants the addressee to bring about by help of the answer, namely a new epistemic state. For simple propositional questions the presupposition is of the form $B \vee \sim B$, and the desideratum is of the form $K_I B \vee K_I \sim B$, where K is the knowledge operator, indexed for the inquirer I. For wh-questions, such as those ranging over persons, places, times, or pointer-readings, the presupposition is $(Ex)B[x]$, and the desideratum is $(Ex)K_I(B[x])$. In the latter cases the inquirer asks the addressee to specify the individual person *x* (or place or time or pointer reading) which has the property B. There may of course be different correct ways of for the addressee to comply, i.e., different ways of specifying the individual.

Thus far so good: erotetic logic, and the epistemic logic of knowledge in which is embedded, promises to fill in a lacuna which we has thus far not been dealt with adequately, namely the nature of questions. Thus on the I-model explanation is improvement in knowledge which proceeds from the initial epistemic state in which the explainee has certain background knowledge. This background knowledge rules out, or makes improbable, those possible worlds in which a certain phenomenon

E occurs (in specified situations, at specified times). When E then occurs, the inquirer's epistemic state is thrown into disequilibrium, manifested by the big question "Why E?" The presupposition of this question is E, and it enters as a premise in the tableau construction depicting the search for an answer.

Two further, related properties of the erotetic idea are relevant for the understanding of the process of explanation. The first one concerns the nature of a conclusive answer to a question raised by I, and hence the product of explanation. The second one extends this analysis to the process. Consider then simple wh-questions which range over, say, persons. An answer to a "Whodunit?" question satisfies a rational ignoramus I if she is, having heard and understood the answer, in the position to say "I know who did it!" However, knowledge comes in degrees. People in fact are often satisfied when they here the name of a person, without actually knowing who that person is. However, a rational *and ambitious* ignoramus who has been raised to appreciate truth and the whole truth is satisfied only if she knows which individual actually did it. A correct direct answer "Eugen Schauman" to the question "Who shot General Governor Bobrikoff" is unsatisfactory to I if I has no clue as to who Schauman was. And clearly, an answer is conclusive only if there are no further pending questions such as "And who the heck was *he*?".

To the extent we can assume that scientific explanations are pursued by rational and ambitious ignoramuses, the analysis provides the key to several obvious facts. To begin with, it gives a crystal-clear logical analysis of what counts as a satisfactory answer. On many views the analysis of this problem is pragmatic, subjective, psychologistic, or anthropomorphic, and on some views irreducibly so. On the I-model, although what counts as a satisfactory answer depends on the tenacity of the inquirer I, on what I happens to know, and on what questions are available in the scientific and cultural context anyway, such pragmatic dependence makes no reference to anything idiosyncratic. In an important sense, then, the I-model continues the research programme of logical analyses of which H-O was one outcome. And of course, precisely this analysis is needed to distinguish logical and pragmatic features of explanation in Hempel's sense: that which is contextually obvious can be omitted from the complete objective answer.

Can anything more be said about satisfactory answers on this general level. What are the requirements for an explanatory answer *überhaupt?*

The built-in requirement that I does not already know the answer (or relevant parts of it) is important, but does not give any positive characterisation of the happy *end state* K_I in which I knows both that E and why E. Although we can derive, from the basic interrogative idea, several further constraints, I suspect that there is no context-free and illuminating general characterisation to cover all possible explanatory tasks. *Some* explanations fit the original Hempelian epistemic format in that they require laws and initial conditions sufficient to make the explanandum phenomenon expected — either with certainty, high probability or at least some probability. However, some explanations — descriptions of stranded or isolated phenomena — fit an entirely different pattern, for they require an answer which enables I to pigeonhole them in a certain category, or in general, which enable I to unite the phenomenon to other phenomena.

It seems to me that one logical/pragmatic-divide runs here, and that there are distinct types of explanation. And I consider it a great merit of the I-model that the question-answer-relationship is formulated on a level which does not commit us to any specific mode of explanation as the only possible one. This not only helps to avoid the hybris of trying to solve all problems in one fell swoop, but also gives a unified account of theories of explanation. Just consider the three major types of explanation singled out by Wesley Salmon, the epistemic, the ontic, and the modal views, where the epistemic views include the erotetic or interrogative views as variants (Salmon 1984). In the I-model these all can be given an erotetic characterization. The general question-answer-relationship is valid in all, but can be cashed out in different terms, as answers which give more expectedness, display necessity, or specify mechanisms.

Notice also that with I-analysis also the question whether explanations are arguments (Hempel), singular descriptive statements (Scriven), displays of statistically relevant properties (Jeffrey and early Salmon), ideal explanatory texts (Railton), answers to why-questions (van Fraassen), or whatnot, can be resolved, or at least rephrased. Explanations are answers, but although the I-analysis does specify some procedural constraints (through the deductive and interrogative rules), and although it gives a characterization of adequate analyses of answers in terms of epistemic conditions, it does not attempt to give a transcendental argument for the size and shape of all possible explanatory answers.

7. *Does Nature Understand Why-Questions?*

I have displayed the virtues of the I-model at some length, so that the reader can appreciate what we will miss if it does not work. And indeed it can be argued that it doesn't, because it gives no account of the peculiar nature of why-questions. In fact, the objection is that nature does not literally speaking understand questions at all, and that it is particularly helpless in the face of explanation-requiring why-questions. If this objection stands, the basic idea of the I-model of explanation is not just an illicit metaphor, but a harmful one at that.

Let us look at this worry more closely. The idea of inquiry as questions put to nature was dear to some forerunners of modern empirical inquiry, such as Francis Bacon. Bacon gave syllogistic logic credit for its power to systematize existing knowledge, but questioned its credentials in the search for new knowledge. He wrote that science starts when man puts 'nature to the question', and advocated experiment and observation as an alternative to reading the Philosopher's books, that is, as the means for reading (and interpreting) the book of nature.

But this is of course just a metaphor. Although nature responds to the inquirer's interventions in experimental contexts, this dialogue is best described in causal rather than communicative terms. Furthermore, as modern philosophy of science has been keen to point out, nature's answers are always open to conflicting interpretations. And since the onus of interpretation always stays on the inquirer, the metaphor is definitely misleading. Nor is this all. It can be argued that some experiments and observations can be construed as what Hintikka calls Shakespearean questions to nature, that is, questions which offer two alternatives B or not-B from which to choose. Similarly, some of them can be construed as non-propositional wh-questions which take, e.g., singular meter-readings as answers. But, the sceptic says, this does not bring us far in the understanding of explanations. Explanations, we agreed, are answers to why-questions, but nature does not understand why-questions. This would give the ultimate reason why H-O never developed an adequate interrogative logic for the intuitive idea: there is no logic of why-questions to speak of.

The reason why why-questions are resistant to this treatment is that the erotetic analysis only seems to cover situations where the inquirer I understands the question in terms of antecedently fixed alternatives or well-understood categories of answers, and merely needs to know which alternative (in Shakespearean questions and finite which-questions) or particular individual (wh-questions) is the right one. Now *some* why-questions, viz. those which reduce to which-questions, meet this description, but those which require a properly speaking scientific explanation do not. Or at least, if the inquirer I does not have theoretical mastery over a phenomenon E and therefore needs to develop a suitable T' & C, it is not necessarily clear to I even what *kinds* of facts to look for.

In terms of the logic of questions the difficulty is this. Propositional yes-no-questions and wh-questions are transparent to the inquirer I in that here there are simple relationships between questions, desiderata, presuppositions and answers. Thus take the inquirer I's why-question "Who shot General Governor Bobrikoff?" which ranges over persons. The request to the addressee is to bring it about that I knows who killed Bobrikoff, or to make it true that (Ex)K_I(x shot General Governor Bobrikoff), or in short, (Ex)K_I(B[x]). The presupposition of the question is simply (Ex)(B[x]), i.e., that someone shot Bobrikoff. Direct answers of the form B[a], B[b] are in turn obtained from presuppositions by substituting names or descriptions of individuals *a*, *b* for *x*, and by dropping the existential quantifier. Clearly, a direct answer does not necessarily satisfy a demanding I, but if I either knows who *a* is or is told that to I's satisfaction, the direct answer plus this further piece of information establishing the person's identity together entail the desideratum. In general, direct answers to questions entail their presuppositions, and answers together with the conclusiveness condition entail the conclusive answer.

The neat feature of wh-questions is that a full-fledged member of the language community generally knows when the conclusiveness condition is satisfied. Furthermore, precisely because there are these logically transparent transitions between questions, answers, presuppositions and desiderata, a rational I knows exactly what kind of entity would count as a conclusive answer. But explanation-seeking why-questions do not have neat presuppositions, their desiderata are phrased in looser terms, and there is uncertainty about their conclusiveness conditions.

Sylvain Bromberger (1987) has argued that the reason for this is that why-questions do not have midsentence-traces, and hence there is a failure of mutual entailment between the questions and their (attributive) presuppositions. It follows that a rational ignoramus (Bromberger's term) in the predicament of knowing that E but not knowing why, cannot infer, on the basis of her knowledge of language alone, what would count as an answer. The knowledge needed is metaphysical knowledge, as well as more tangible knowledge usually served in the form of theories. And there is a complication we must add, if Bromberger is right: what counts as a legitimate question and as an admissible or good answer to the question may be highly contextual, if not entirely up to social conventions.

I have previously suggested that this is as far as logic can take us, and that further help can only be obtained from explorations out in the world, in the form of theories sufficiently strong to narrow down admissible answers (Sintonen 1989). This would mean that the weak logic of why-questions must be supplemented with a strong theory-notion, so that theories can give heuristic guidance as well as constrain answers. There is much truth to this. However, this does not mean that the resources of the I-model have been exhausted, precisely because it *is a model which tells us how the world out there can be explored and conquered.* The suggestion is that the I-model tells us how answers to why-questions are sought. And it does this by showing how why-questions are sliced into which-questions, and again into yes-no-questions. The process of searching for explanations is, naturally, messier than assessing already proposed candidates. But this we already know: whoever thought that inquiry is easy?

8. *From Why-Questions to Shakespearean Questions*

To see the I-model in action, consider the discovery of the theory of natural selection. Both discoverers, Darwin and A. R. Wallace were inspired by Malthus's *Essay on Population*. The constant discrepancy between the demand for food and available supplies necessarily resulted in a struggle over limited resources. Whereas the supplies only increase arithmetically, populations grow in a geometrical ratio, if not kept in balance, that is. And according to Malthus wars, famines, infanticides, epidemics, plagues, and like catastrophes are needed to keep human populations in balance.

From the perspective of the I-model the interesting observation is that Darwin clearly started from the big initial question of why and how species come into existence and then go extinct. This was "the mystery of mysteries" which he tackled very methodically, with an enormous quantity of background knowledge at hand. But how did Darwin put the pieces together, what method did he use to revise background knowledge, and what were his strategies in finding new knowledge? And: was there a logic?

The answer seems to be that Darwin employed in a skilful fashion the I-model of inquiry. He constantly put questions to fellow scientists and to himself, as is well documented in his autobiography and correspondence. But apart from this he also put questions to nature, that is, experiments. Thus when he needed to know, for the purposes of his emerging theory, whether seeds could travel and survive in icy streams, he designed ingenious Shakespearean questions and addressed them to nature and fellow inquirers. His published books, correspondence, and published and unpublished notes were full of queries relevant for the initial big question.

The way of questions and answers is not only manifested in the discovery of the theory, for Darwin also used it as an expository device. The first chapters of *The Origin*, and the famous passage in which its results are summed up, are phrased in question-answer terms. The discussion begins with singular and general questions concerning variation in animal breeding, and then proceeds to establish its analogue in nature. The preliminary fact-exposing arguments then turn to establishing the principles of the struggle for existence and heredity. And Chapter IV opens with the questions "How will the struggle for existence, briefly discussed in the last chapter, act in regard to variation? Can the principle of selection, which we have seen is so potent in the hands of man, apply under nature?" And somewhat later: "Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life, should occur in the course of many successive generations." (Darwin 1859, p. 63-64).

The results from the interrogative derivations for the principles of Variation, Inheritance, Variation in Fitness and Struggle for Existence were then pooled into an argument for the Principle of Natural Selection in Chapter IV, represented below as conclusion (20). An edited reading, one which makes the questions to nature (or to the shared data pool) explicit, goes like this (for further discussion, see Sintonen (1990):

(1) Is there variation in domestic animal breeds?

(2) Yes there is.

(3) Are some of these variations inherited?

(4) Yes they are.

(5) Are some of these variations useful for the breeders?

(6) Yes they are.

(7) Is there competition between variations for food and sexual partners.

(8) Yes there is.

(9) Are these variations more likely to survive and leave offspring?

(10) Yes they are.

(11) Is there variation in nature?

(12) Yes there is.

(13) Are some of these variations inherited?

(14) Yes they are.

(15) Are some of these variations useful for the beings?

(16) Yes they are.

(17) Is there competition between natural variations for food and sexual partners?

(18) Yes there is.

(19) Are these variations more likely to survive and leave offspring?

(20) Yes they are.

But, it may be objected, although this passage may show how an interrogative (here it has been left informal) derivation is put together, once the principles are at hand, it does not suffice to show that the I-model in any way helps us to understand the reasoning that lead to them. Nor does it tell anything about why-questions.

But this scepticism is not quite justified, for the reasoning from (1) to (10) functions as an analogy for the reasoning from (11) to (20). What the analogy does is bring in new individuals, properties, relationships to the inquirer I's attention, to be entered on the left-hand side in the tableau, as presuppositions for further questions. This way of putting it is not far from the plausible view that analogies feed in questions. For if there is an analogy between a known and an unknown system, there are both positive and negative analogies between them. But apart from these there are what Mary Hesse (1970) calls neutral analogies whose status is yet unknown: it is possible, for all the inquirer knows, that the same or similar individuals, properties and relations can be found in the unexplored part of the system studied. What the I-model does is make it explicit that these hunches, possibly precarious, literally can be turned into questions to nature.

The import of the I-model is even more easily seen in the interrogative path to the selection theory traversed by Wallace. Wallace was not impressed with the analogy with domesticated animals, because he saw the force of the disanalogy. But here also Malthus's theory served as a midwife by suggesting the mechanism: twenty years after reading the book it gave Wallace "the long-sought clue to the effective agent in the evolution of organic species". Wallace's train of thought, no doubt a little tidied in retrospect, nicely shows how the I-model can be extended to why-questions. For what theories do, among other things, is this: they process unmanageable why-questions first into which-questions, and then into Shakespearean questions.

Thinking about Malthus's account of human populations Wallace realized that the same or similar forces might also shape animal populations. And since animals breed more rapidly than man, and since evidence shows that they do not increase regularly each year, the magnitude of destruction each year must exceed that in human populations. "Otherwise," he wrote, "the world could long ago have been densely crowded with those that breed most quickly". And he writes (Wallace 1905, I, 361-363):

> Vaguely thinking over the enormous and constant destruction which this implied, it occurred to me to ask the question, Why do some die and some live? And the answer was clearly, that on the whole the best fitted live. From the effects of disease the most healthy escaped; from enemies, the strongest, the swiftest, or the most cunning; from famine, the best hunters or those with the best digestion; and so on. Then it suddenly flashed upon me that this self-acting process would necessarily improve the race, because in every generation the inferior would inevitably be killed off and the superior would remain — that is, the fittest would survive. Then at once I seemed to see the whole effect of this, that when changes of land and sea, or of climate, or of food-supply, or enemies occurred — and we know that such changes have always been taken place — and considering the amount of individual variation that my experience as a collector had shown me to exist, then it followed that all the changes necessary for the

adaptation of the species to the changing conditions would be brought about ... The more I thought over it the more I became convinced that I had at length found the long-sought-for law of nature that solved the problem of origin of species ..."

Again we can see, in Wallace's internal dialogue, the interrogative procedure which not just codifies available knowledge but is directed towards acquisition of new knowledge. There are the analogies feeding in questions, but the passage on the whole shows more. Wallace indicates that the interrogative process started with the problem of origin of species, the big question. But the analogy also suggests a further why-question which is instrumental in the discovery of the mechanism: "Why do some die and some live?"

Now this question is not accessible to nature, for there is no way in which one could address it to nature directly. However, the why-question does recommend a look at organisms in different circumstances. Having followed this recommendation Wallace was able to split the initial why-question into series of wh-questions, such as 'Who would survive diseases?' and 'Who would survive enemies?' And when these questions are further processed to more specified types of circumstances, the result is a series of wh-questions and Shakespearean questions *which are accessible to nature*. This is reassuring for any interrogative view, for two reasons. For one, it means that the logic of questions can be extended to why-questions, though perhaps only indirectly, because transparent conclusiveness conditions for answers do hold for the derived wh- and yes-no-questions. Secondly, as the example of Wallace's reasoning shows, this indirect access to why-questions allows the inquirer to climb back, in a synthetic move reminiscent of traditional analyses of scientific method, to an answer to the big initial question.

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NOTES

1. There are also what Hintikka calls definitory moves, but I shall omit them in what follows. I should add that the account of erotetic and epistemic logic employed here is essentially the one given in Hintik-

ka (1976). Hintikka and his associates have since developed what is called independence-friendly logic (IF-logic) which gives a more satisfactory and unifying account of epistemic and erotetic logic. I have chosen to keep within the confines of an extremely simple account and notation, basically because many of the applications of the I-model are independent from IF-logic, and can be represented in a perspicuous way without it.

2. I have discussed these issues in more detail in Sintonen (1989). See also Lloyd (1987) for an excellent discussion of the construction of ecological and other models.

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