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Diagnostic Reasoning in Action

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Abstract. The task of diagnosis is a very important topic in many different contexts. In high complex technical installations involving high hazards such as process plants diagnosis is a crucial part of disturbance control; in technical maintenance, diagnosis is necessary to locate the root cause of system failures, and in medicine, diagnosis is the basis for any patient treatment. The paper presents a discussion of the basic nature of causal reasoning as applied for diagnosis and the mental strategies applied when diagnosis is viewed as an integrated part of "natural decision making" for interaction with the environment. A typology is suggested to characterize diagnosis in different domains such as process control, maintenance and medicine. In addition, an attempt is made to distinguish between the features of diagnosis depending on the ultimate aim, whether it is explanation, compensation, repair, or punishment and the difference in the context of the task, "the causal field," related to the mental model involved in the different cases is outlined.

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TABLE OF CONTENTS

1.INTRODUCTION

The basic meaning of the term "diagnosis" is, according to Webster: "the act or process of deciding the nature of a diseased condition by examination", or: "a careful investigation of facts to determine the nature of a thing." This definition is focused on diagnosis as an analytical process, separate from the planning of the ultimate act based on the outcome of the diagnostic effort and its definition is closely related to the academic approach to the study of medical diagnosis. In the present paper, diagnosis is considered in a wider context including its role in action. Consequently, it appears that a more appropriate definition is the original connotation which, also according to Webster, originates from Greek: "dia gignoskein," i.e., "knowing the difference." That is, diagnosis involves the act of distinguishing one case from another, of separating a relevant item from the general context or background. In that sense, diagnosis basically is closely related to categorisation, to the act of labelling. From this it is immediately clear, that in order to describe the act of diagnostic judgement, it is essential to determine, *what* is subject to categorisation and, as well, *why* is the categorisation made.

Even in an "objective" attempt to classify and to give a name, the diagnostic context is essential: The decomposition of the world into elements to classify and the choice of attributes for classification depend on the particular point of view applied by the categoriser: A biologist and a cook classifying plants and animals will apply quite different classes, based on completely different attributes, as already pointed out by Linné (1735). In other words, the purpose and the related point of view define the classes and their attributes or, in the terms chosen below, the relevant diagnostic field.

In conclusion, to be able to describe the diagnostic process, it is necessary to consider carefully the object world in which the categorisation will take place and, as important, the context in which an actor finds himself, i.e., the goals and the repertoire of alternative actions, relevant in the diagnostic situation.

2. BASIC ISSUES

To set the stage for a detailed discussion, some basic issues will be reviewed in the following paragraphs. First, the difference is considered between diagnosis viewed as a separate decision task and as an integrated part of the cognitive control of goal directed actions.

2.1. DIAGNOSTIC JUDGMENT IN THE LABORATORY

Diagnostic behaviour has been studied extensively within the social judgement paradigm, normally by an analysis of the utilization of the available cues in laboratory judgment tasks. This approach has been used to study diagnostic judgment in several professional activities such as stockbrokers, clinical psychologists, and physicians (see e.g., Brehmer, 1981). In experiments, cues identified as diagnostically relevant by expert judges are used to prepare trial cases to present to subjects, generally in the form of cards with sets of attributes. From this evidence, a statistical model describing diagnostic behaviour is developed. The general result has been that linear statistical models, such as multiple regression analysis, have been adequate. Four characteristics of expert judgment are typically found by such experiments. First, the judgment process tends to be very simple. Even though experts identify up to 10 attributes or cues to be relevant to diagnosis, they actually use very few, usually only two or three, and the process tends to be purely additive. Second, the process tends to be inconsistent. Subjects do not use the same rule from case to case, and judgment in a second presentation of a case may differ considerably from the first time. Third, there are wide individual differences even among subjects with years of experience. They differ with respect to the cues used and the weights they apply. The fourth general result is that people are not very good at describing how they make judgments (Brehmer, 1981).

A very similar approach to the study of diagnostic reasoning has been taken in medical philosophy (Wulff, Pedersen, and Rosenberg, 1986). Diagnosis has been defined as the act to seek, isolated from the application context, the attributes necessary for classification of a "case." The theoretical basis has been influenced by the causal theory of Mackie (1975), as discussed in a subsequent section.

2.2. Multi-Attribute Judgment and Diagnosis in Action

However, analyses of the diagnostic judgement in an actual work context tend to paint a different picture. Comparing the results of laboratory studies with our analyses of diagnostic tasks in hospitals and repair shops, we can identify some important differences which will signal great caution for transfer of the laboratory results to the actual professional work context and call for a wider definition of a "diagnosis." This statement does not imply that the results of laboratory experiments are not valid for multiple attribute judgement tasks, but rather that isolated multiple attribute judgement is not always a characteristic of a real-life diagnostic judgement.

First, the experimental design suggests that decision makers are subject to an information input which they have to process. The task is isolated from its normal context and, therefore, the 'tacit knowledge' of the subject has no opportunity to be synchronized. In actual work, subjects are emerged in the situational context and they are, therefore, tuned to ask focused questions to the environment, rather than to process multiple attribute sets. The various features of the context through time, serve to up-date the 'attunement' of the organism, to speak with Gibson (1966), or to synchronize the "internal, dynamic world model" (Rasmussen, 1986).

Second, in actual work, a diagnostic judgment is not a separate decision task but intimately connected with the subsequent choice of action. Diagnostic judgment for action is not a theoretical categorisation of the observed data, but a search for information to select, among the perceived alternatives for action, the one matching the case in question. Models of decision making are normally structured such as to be a sequence including situation analysis, goal formulation and priority judgment, and planning. This normative sequence is the basis of the decision ladder in figure 1.

Experts in action, however, have a repertoire of heuristic short-cuts by-passing the higher levels of the ladder. In any familiar situation, they only perceive a small number of alternative plans - this is the core of expertise - and they only need information enough to resolve the choice among those plans. Therefore diagnosis and action is intimately connected.

These two aspects of real life diagnosis are illustrated in figure 2 representing the sequence of diagnostic judgements with respect to one patient's treatment in a hospital. It is clear that diagnosis is more of an element in a dynamic control task than it is an isolated resolution of a multi-attribute judgement problem. One important issue is that irrespective of the stability of the patient's condition, the diagnosis has to be repeated many times, because the judgment is connected to different sets of action alternatives and a diagnosis made in one situation, therefore, may be unreliable for a later decision.

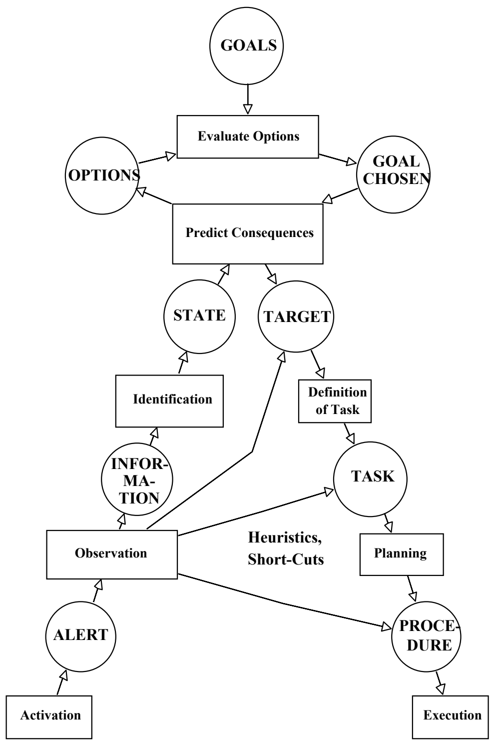

Figure 1. The figure illustrates the sequence of basic information processes in a decision task together with a number of heuristic short-cut paths. It serves to identify a number of basically different decision functions which are used to connect different "states of knowledge" with respect to the activity in the work domain. The figure is used in our field studies as a sketch pad for representation of the interaction of situation analysis, goal evaluation, planning and action, and for indication of "recognition primed" short-cuts, see figure 2

If the categories to consider are defined by the context in terms of the relevant action alternatives, then the attributes to consult, in addition to be dependent on the state of the object of diagnosis, they also to a large degree depend on the aim of the diagnostician and the context, that is, the nature of the diagnostic field. The lesson to be learned from this discussion is that an analysis of the diagnostic process must be based on a wider definition of the diagnostic task, it must consider the actual context of decision making, and it must take into consideration the different modes of natural decision making.

Figure 2 represents medical diagnosis in hospital context and illustrates several features of "naturalistic decision making: 1.The different phases of decision making, such as situation analysis, goal evaluation and planning are intimate connected. Diagnosis, therefore, cannot be separated as an isolated activity. 2.Diagnosis is repeated several times, and the process depends on the question asked, i.e., whether to hospitalize and whether, when, and how to operate. Diagnosis is a choice among the perceived action alternatives, not an objective decision process. 3. The total process is not a linear sequence, but a complex communication network. The arrows indicate the transfer of information among the various diagnostic phases.

2.3. DIAGNOSTIC JUDGMENT IN NATURAL CONTEXT

Diagnostic judgment in the present context is taken in its wider meaning of categorizing the state of affairs in the environment with respect to selection of the proper action towards some target or goal. The concept of diagnostic judgment in this way implies the first phase of decision making in a natural context which, in the normative case, includes situation analysis, goal selection and action planning. In a familiar context, decision making and planning degenerate into cue-action chaining. It is, therefore, essential to consider the fact, that "decision making" and, consequently, "diagnostic judgment" will take place with reference to different levels of cognitive control of action in a dynamic environment and to different domains of action.

In familiar context, skilled behaviour unfolds as an integrated, continuous flow with no need for interrupt and discrete decisions and relies on data-driven chaining of movement patterns generated by an internal, dynamic representation of the context of behaviour, i.e., of the environment. However, conscious mental operations, 'decisions,' can play an important role by preconditioning the required dynamic representation. Such preplanning can by done by recall of previous, similar activities and situations in advance and rehearsal of likely, useful action scenarios together with preview of the expected points in time when choice between action alternatives will be required. This will serve to introduce land marks in the simulation scenario of the internal world model and to prepare it for the proper cues for choice. In this way, intuition can be prepared for the events to come, and the actual decision making then becomes "recognition primed decision" (Klein et al., 1986, Klein, 1989) for which no action alternatives are considered *at the time of action*. In hospital context, we have observed a related kind of natural decision making not taking explicitly into consideration the available alternatives of action. In our case, operation theatre planning was done during conferences including doctors and nurses. A typical feature of the hospital system seems to be a kind of collective memory; no one person has available all the relevant information about the individual patients, but a kind of 'collective mind' has the adequate information. When treatment of an individual patient is planned, the context established by previous cases and meetings defines an elaborate knowledge background. If, at a particular meeting, an action is proposed which is not supported by the knowledge possessed by some member of the group, this will be voiced properly. If the situation is ambiguous, group members very likely will offer comments serving to specify the context in a better way. This goes on until the context is properly established and decision can be concluded by the surgeon in charge without alternatives being explicitly mentioned. In other words, action emerge without choice when the context is complete.

This kind of high-skill decision making depends on the conditioning in advance of the internal world model which is required to generate automatically the proper behavioural pattern on occasion. When the conditioning as described has not been effective, mismatch can be experienced by the person, between the state of affairs in the environment and the predictions by the internal world model. In this case, a number of alternatives for action may be perceived, and the environment will be consulted to read a sign which can resolve the ambiguity. For diagnostic judgement, this means that the information sought, the attributes consulted, will depend strongly upon the action alternatives perceived to be available for adjustment of the state of affairs in the light of the current objective. This perception will depend on the perceived consequences of the alternative actions available. e.g., the perception of the involved risk of failure and punishment. In the medical context, the risk of law suits has been very influential and the trend toward DRG, Diagnosis Related Groups (Hall, 1988), as a basis for financial planning will probably have a significant influence on the actual diagnostic performance in the direction of a normative strategy which can be explicitly justified after an unhappy fact.

If an acceptable set of action alternatives is not available, recall of prior similar cases can, as mentioned, assist in the identification of the relevant actions and their activation cues. If no resolution is found in this way, and only in this case, resort will be taken to the analytical mode of diagnosis and knowledge-based decision making which has been the focus of most academic research.

2.4. DIAGNOSTIC JUDGEMENT AS CATEGORISATION

It follows from this discussion that diagnostic judgment in the present context is taken to be an identification of the state of affairs in the environment with reference to the actions relevant for the immediate objective. Diagnostic judgment implies the perception of a causal relation between a state, an action, and the ultimate effect, as related to the current objective. All possible, particular causal relations cannot be stored for retrieval in each particular situation and, consequently, diagnostic and causal reasoning for choice of actions depends on *relationships among categories*, i.e., types of states, events, and actions, even if the actions chosen in a particular situation will controlled by the given state of affairs.

Categorisation depends on the formation of clusters in a *universe* of elements. Generally, this universe is not constituted by elements defined in isolation. Formation of the elements to categorize depends on a decomposition of the context or an aggregation of primitives, i.e., the level at which elements are chosen is discretionary and subject to choice. It is necessary to identify this universe within which the categories are defined. This is, in the subsequent sections, called the causal or diagnostic field. Furthermore, it is necessary to consider the way in which the categories are chosen, i.e., how the *decomposition* within the universe is chosen with respect to the terms as well as to the resolution. When diagnosis is related to choice among the action alternatives, then the activation of the context of judgment, i.e., the universe and the definition of categories within this universe, will be guided by the *objectives* relevant in the particular situation.

Categorisation and Causal Reasoning

Under some conditions, causal reasoning is an important issue in the diagnostic task and a discussion of the nature of causality will be useful. Bertran Russell (1913) discussed the characteristics of causal reasoning in contrast to scientific reasoning.

A classical *scientific analysis* is based on mathematical equations relating physical, measurable variables. This approach depends on a selection of relationships which, in Russell's terms, can be 'practically isolated.' This separation is possible if the relations are isolated by nature (e.g., as they are found in the planetary system) or because a system is designed so as to isolate the relationship of interest (e.g., by a scientific experiment or in a machine designed to support a physical process in a controlled way). In this kind of representation, material objects are only implicitly represented by sets of parameters of mathematical equations. The representation is particularly well suited for the analysis of the optimal conditions and theoretical limits of physical processes in a technical system which, by its very design, carefully separates physical processes from the complexity of the outside world.

Causal reasoning, on the other hand, depends on regular connections of events in time. Causal representations are found in terms of the propagation of events in the environment, i.e., changes of the states or configurations of objects. Russell emphasises the ambiguity of the terms used to define causality: the necessary connection of events in time sequences. The concept of an 'event,' for instance, is elusive: the more accurate the definition of an event, the less it is likely that it is ever repeated. Completeness removes regularity. The solution is not, however, to give up causal explanations. Representation of the behaviour of the physical world in causal terms is very effective for describing accidents because the objects of the real world are explicitly mapped by the model and changes, such as faults, are easily modelled. This is the case because causal reasoning is related to changes in the normal context as experienced by the analyst. Therefore, rather than to give up causal explanations, as Russell requests, or to seek objective definitions of events, it must be realized that regularity in terms of causal relations is found between kinds of events, between types, not between particulars, i.e., individually defined events or tokens.

Russell's distinction is based on a definition of cause and effect as being consecutive events in a conditioned environment. This point of view is focused on the relationship among events. "Causes" are discrete antecedents of other events. In consequence, laws of nature, such as e.g., gravitation, cannot be a 'cause.' To talk of the gravitational force as the cause of the movement of a grandfather clock is a category mistake, mixing concepts from Russell's two classes: causal and deterministic models. The gravitational force does not 'cause' but it 'determines' the movement of the clock mechanism. Measuring time is the 'reason' for the presence of the clock. The 'cause' of the motion of its parts is the owner's push of the pendulum after winding the clock.

The present point of view is that causal reasoning is important for scientific as well as practical reasoning because of its direct mapping of objects and because it maintain a unified representation of the properties of objects and, therefore, is well suited to represent changes of the properties of objects, e.g., as an effect of human actions.

When events and objects found in causal representations cannot be defined by an exhaustive list of attributes, they can only be understood as being prototypes representing classes defined with reference to the shared context as defined by the tacit knowledge of the community within which the causal model is the accepted basis of communication.

The behaviour of the complex, real world is a continuous, dynamic flow which can only be explained in causal terms after decomposition into discrete events. The concept of a causal interaction of events and objects depends on a categorisation of human observations and experiences. Perception of occurrences as events in causal connection does *not* depend on categories which are defined by lists of objective attributes but on categories which are identified by typical examples, prototypes (as defined by Rosch, 1977). This is the case for objects as well as for events. Everybody knows perfectly well what 'a cup' is. To define it objectively by a list of attributes that separates cups from jars, vases and bowls is no trivial problem and it has been met in many attempts to design computer programs for picture analysis. The problem is, that the property to be 'a cup' is not a feature of an isolated object but depends on the context of human needs and experience. The identification of events in the same way depends on the relationship in which they appear in a causal statement. An objective definition, therefore, will be circular.

A classical example has been given by Mackie, as discussed below. His statement, that "the short-circuit caused the fire in the house" is a record of a particular case. In the general sense, its significance is to interrelate two prototypes: the kind of short-circuit that can cause a fire in a particular kind of house. The explanation that the short-circuit caused a fire may be immediately accepted by an audience from a region where open wiring and wooden houses are commonplace, but not in a region where brick houses and piped wiring are the more usual reality. If the explanation is not accepted, a search for more information is necessary. Short-circuits normally blow fuses, therefore further analysis of the conditions present in the electric circuit is necessary, together with more information on the path of the fire from the wiring to the inflammable elements of the house. A path of unusually inflammable material was probably present. In addition, an explanation of the short-circuit - its cause - may be needed. The explanation depends on a decomposition and search for unusual conditions and events. The normal and usual conditions will be taken for granted, i.e., implicitly given by the intuitive frame of reference. Therefore, in a causal explanation, the level of decomposition needed to make it understood and accepted, depends entirely on the intuitive background of the intended audience. If a causal statement is not accepted, formal logical analysis and deduction will not help because it will be easy to give counter-examples which are not easily falsified. Instead, further search and decomposition are necessary until a level is found where the prototypes and relations match intuition. (The reason that nuclear power opponents do not accept risk analysis may be that they have an intuition very different from the risk analyst's intuition, rather than a lack of understanding of risk and probability).

Rules for Termination of Decomposition and Search

A conclusion of this discussion is that the very nature of causal explanations shapes backtracking in causal explanations such as diagnosis, e.g., of a particular accident or the disease of a particular patient. Decomposition of the dynamic flow of changes will normally terminate when a sequence is found including events which match the prototypes familiar to the analyst. The resulting explanation will take for granted his frame of reference and in general, only what he finds to be unusual will be included: the less familiar the context, the more detailed the decomposition. By means of the analysis, a causal path is found up-stream from the ultimate effect. This path will be shaped by resident conditions which are latent effects of prior events or acts. Also these resident conditions can be explained by causal back-tracking and in this case branches in the path are found. To explain a particular case, such branches are also traced backward until all conditions are explained by abnormal, but familiar events or acts. The point is: how does the degree of decomposition of the causal explanation and the selection of the side-branches depend on the circumstances of the analysis? Another question is: What is the stop-rule applied for termination of the search for causes? Ambiguous and implicit stop rules will make the results of analyses very sensitive to the topics discussed in the community involved at any given point in time. There is a tendency to accept as explanation what you expect to find. For example, during one period of industrial safety concern, technical faults were in focus as causes of accidents, then human errors were predominant, presently the focus is moving up-stream towards errors of designers and managers (Rasmussen, 1990b). For medical diagnosis, similar fashions have been identified (Burnum, 1987). This points to the question whether accidents and diseases are related to higher level functional structures and feedback mechanisms rather than to local causal connections. In that case, traditional causal attribution turns out to be fighting symptoms rather than the structural origin of break-down. This raises the question of generalisation which is discussed in a subsequent section.

Stop-rules controlling termination of search are not usually formulated explicitly. The search will typically be terminated pragmatically in one of the following ways: (a) An event will be accepted as a cause and the search terminated if the causal path can no longer be followed because information is missing; (b) A familiar, abnormal event is found to be a reasonable explanation; or (c) A cure is available. The dependence of the stop rule upon familiarity and the availability of a proper action by the analyst makes the judgement very dependent upon the role in which a judge finds himself. The implicit nature of the stop rule frequently influences studies of the causes of accidents. In analysis of anaesthetic mortality, for instance, two concepts are used to categorize causes, i.e., the blame concept (something has been done incorrectly) and the event concept (something has happened) and studies have frequently used mixed categories (Dubberman et al. 1986).

To summarize: identification of the cause of a particular case is controlled by pragmatic, subjective stop-rules. These rules depend on the aim of the analysis, i.e., whether the aim is scientific, that is to explain the course of events; legal, that is to allocate responsibility and blame; or therapeutic, that is to identify possible improvements in order to avoid similar future cases.

Mackie's Causal Theory

In the philosophical literature, in particular Mackie (1975) has made an attempt to formalize the properties of causal explanation described in the previous paragraph. These theories have recently been used to formalize medical diagnosis by Wulff et al. (1986).

Singular Causality

Mackie presents a classical example very well suited to illustrate the prototypical nature of events and causes as discussed in the previous paragraph: "the short-circuit caused the fire in the house." This statement is a record of a particular case but Mackie formulates the INUS concept for a causal explanation of such a singular course of events. His example presents a causal complex which is an Insufficient but Necessary condition for the fire. This complex is an Unnecessary (houses can burn from other causes), but Sufficient cause of a fire. Since short circuits normally blow fuses rather than cause fires, acceptance of the conjecture implies the formation of a particular context including presence of easily inflammable material etc. Or, as Mackie phrases it, the necessity of a particular "causal field" from which the argument is drawn. Mackie explicitly explains how the choice whether a condition should be part of the causal argument or can be assumed to be part of the field depends on the circumstances or, according to the previous discussion, it depends on the degree to which the partners involved in a discussion share a common intuition.

Mackie's example relates to an analysis of a singular case, but the argument presupposes general, causal relationships. If no generality is found in the relationship between short-circuits and fires, the statement would have no explanatory power. Therefore, the short-circuit and the house mentioned must be considered prototypes which make sense of the statement, i.e., they are only valid in the particular causal field.

The INUS condition defines a complex of and-gates: each entry identifying a necessary but insufficient condition for a particular case. Several such complexes are "sufficient" and "unnecessary" in the general case. Several complexes potentially have similar effects and go together in a general causal tree (figure 5). The problem is, as also realized by Mackie, that there is no stop criteria for search for conditions to require present or for possible interventions to assume absent in the general case. The representation is based on empirical evidence with an intuitively accepted level of completeness, i.e., the context of the analysis is implicitly given. The set-relationships are only empirically found to be valid, and counter examples can always be proposed for a particular "causal field."

General Causality

Mackie discusses the nature of the statements in causal arguments and the problem of generalizing from singular causal arguments. He notes, related to the generality of the short-circuit example, that "a direct analogous account of the corresponding singular statements is not satisfactory."--- "It is much more plausible to relate singular statements about necessity and sufficiency to certain *kinds* of non-material conditionals." In this way, he accounts for the prototypical nature of causal arguments brought forward in the previous sections. He continues: "However, a further account would still have to be given of these non-material conditionals themselves. I have elsewhere argued that they are best considered as *condensed or telescoped arguments*, but that the statements used as premises in these arguments are no more than simple factual universals. ----- In each case the argument might in principle be completed by insertion of other premises which, together with the stated premises, would entail the stated conclusion."

Decomposition: "Condensing and Telescoping"

In this way, the level of decomposition of a causal argument has also been considered by Mackie. He mentions the freedom for the "condensing" or the "telescoping" of causal arguments. His arguments are similar to the arguments in the previous section about the proper level of decomposition in the discretization required for causal explanations. The process of "condensing" elementary arguments can involve a shift to classes which are super-ordinate to the directly observed causal connection. On the other hand, a complex sequence of causal arguments deduced from a functional model can be condensed to a simpler set of causal relations which can handled afterwards by set theory and logic.

Mackie realizes that in set-theoretic, logic arguments, the direction of causality is a difficult question: "This account of causation is still incomplete, in that nothing has as yet been said about the direction of causation,--"

3. DIAGNOSTIC STRATEGIES IN ACTION

To prepare for a more detailed discussion of the different kinds of diagnostic fields which are found in actual work context, a discussion of the nature of diagnostic strategies will be useful.

IDEALIZED AND NATURAL STRATEGIES, A TYPOLOGY

A clarification of the concept of strategies is important here. In the present context, a particular "strategy" is taken to be one idealized category of cognitive processes. All of the particular implementations of a strategy will be different, but will share a particular kind of mental model, a certain kind of interpretation of the observed evidence, and a coherent set of tactical planning rules. In consequence of this definition, different strategies require very different resource profiles of an actor with respect to mental models, a priory knowledge, empirical evidence, etc. From this point of view, a "strategy" is an abstraction in terms of an idealized, normative diagnostic inference procedure. Performance in an actual work situation, in contrast, depends on "natural strategies" and involves frequent shifts among idealized strategies in order to resolve local demand-resource conflicts. The formulation of a set of coherent, idealized strategies is necessary for the establishment of a framework for a formal description of the complex task of the diagnostic reasoning in an actual work context.

In order to clarify the nature of diagnostic reasoning and the implications of these basic issues, it will be useful to have a look at different diagnostic strategies, as they have been identified from field studies. There are many possible ways to characterize such strategies. In the present context the focus of interest is the implication of the nature of causal reasoning and, consequently, a particular approach to a typology is discussed in the subsequent sections.

DIRECTION OF INFERENCE

The first distinction is related to the *direction of inference* involved in the diagnostic reasoning. Here three categories are found to be relevant:

1. Going from the normal functionality to the actual abnormal case: This is the analytical variationist approach, by which judgment is made with reference to a normal, designed state of affairs independent on general, empirical evidence.

2. Going from the general picture to the specific case: Judgment is based on instantiation of empirically established, general causal relations:

3. Going from the specific case to the general statements: Judgment is concerned with generalization, going from evidence about a particular case to judgment about general causal relations.

In the following sections, a number of diagnostic strategies are reviewed with reference to the features of causal reasoning discussed in the previous sections.

3.1. FROM NORMAL CONDITION TO ACTUAL CASE: THE ANALYTICAL VARIATIONIST APPROACH

This set of strategies involves judgment of an observed disturbed or abnormal case with reference to the normal state of affairs within the object of diagnosis or to the intended (e.g., designed) normal functional structure. Inferences in the diagnostic task will typically be made independently of general, empirical evidence from prior cases of faults, accidents, or diseases. This class of strategies is very effective for man-made, technical systems which serve well defined purposes by well known functions. The class is, however, also effective for biological systems, e.g., in medicine when reliable models of the normal physiological functions and states have been established.

Different idealized strategies are possible for an analytical variationist approach depending on the *purpose* of the diagnosis.

3.1.1 Analysis for Explanation of a Particular Case

In an analysis to explain an accident in a technical installation, the course of events will be followed backwards from the ultimate effect. As mentioned above, the nature of causal reasoning will require the backtracking to be continued until a cause is found which is familiar to the analyst. If a technical component fails, a component fault will only be accepted as the prime cause if the failure of the particular type of component appears to be 'as usual.' Further search will probably be made, if the consequences of the fault make the designer's choice of component quality unreasonable, or if a reasonable operator could have terminated the effect, had he been more alert or been better trained. In such a case, a design or manufacturing error, respectively an operator error will be accepted for explanation.

In most recent reviews of larger industrial accidents, it has been found that human errors are playing an important role in the course of events. Very frequently, errors are attributed to operators involved in the dynamic flow of events. This can be an effect of the very nature of the causal explanation. Human error is familiar to an analyst: "To err is human." However, the high skill and efficiency of professional people normally depends on their ability to depart from instructed procedures. To work according to rules has been an effective replacement for formal strikes among civil servants. It is therefore very likely that an analyst after the fact will find departures from instructed procedures and, thus, identify errors in the stream of events.

The *diagnostic field* in which the course of events will be traced is the normal physical anatomy of the system, normal, causal input-output relations for technical components and equipment, and the instructed operating procedures applied for control of the system by the staff. Understanding the abnormal state involves identification of a change with respect to the normal functioning of a particular piece of equipment which is familiar to the diagnostician. The course of events is identified as the propagation of aberrations with reference to the intended, designed processes of equipment and components. The search will, very likely, be supported by the use of a functional diagram, by calculated performance plots, by instruction manuals, and by other design blueprints. The diagnostic field underlying this class of strategies is independent of empirical evidence from prior cases. One does not need empirical evidence to distinguish failed components from those working properly. The *stop rules* controlling the termination of decomposition and search, however, depend on the subjective experience and level of expertise of the analyst. The more experienced, the higher the level of "condensing" of causal relations can be accepted, and the less detailed will be functional decomposition of the object of diagnosis required for the search.

This kind of diagnosis will also be possible in the medical case; no evidence from prior cases will be necessary for the identification of a broken leg or a physical injury of a human circulatory system.

3.1.2 Analysis for Compensation of a Disturbance

The first concern of an actor faced with an abnormal system will, very likely, be a compensation of the immediate influence on some vital performance parameter of the observed abnormal state. This is the case when a failure disturbs the operation of an industrial process system and thus indicates the possible advent of an accident. In this case, the task is to protect the system and immediately to bring it into a safe state before repair is considered. Similarly, in the medical case, it can be important to stabilize the conditions of an injured victim of a traffic accident, before the ultimate therapy can be considered.

In this case, the aim of the diagnostic search is to identify the endangered system functions and to locate the target of a proper compensating action. This can be done analytically in terms of a causal back-tracking in a representation of the internal functional structure of the system from the observed effect until a point, sensitive to corrective action. The source of the disturbance is only of concern later. In case of fire, you will first look for a bucket of water, not for the possible short circuit.

This kind of causal search is, in particular, possible in case of well-structured technical systems. In such systems, compensatory actions are important for protection of the system against major accidents and damage to the environment. Major accidental damage can only emerge from the loss of control of the major flows of mass or energy and compensatory diagnosis will be focused on identification of means for regaining control with the major mass- and energy- balances of the system. The *diagnostic field* of the search will represent those major flow structures which can cause accidents. Means for control then can be identified from an analysis of the physical process involved in the disturbed balance, irrespective of the cause of the particular disturbance and independent of any empirical evidence from prior cases.

Similarly, in the medical case, stabilization of the state of a patient may depend on control of vital circulatory systems, e.g., stabilization of blood circulation or flow of oxygen, irrespective of the prehistory or cause of the actual condition. That is, the diagnostic field represents the basic circulatory systems of the patient, not empirical evidence from prior cases.

3.1.3 Analysis for Correction of Particular Cases

For the ultimate correction of a faulty condition, the objective is to restore the normal physical state of the system, e.g., by replacing a failed pump or mending a broken leg. Also with this objective, an analytical diagnosis is often possible simply with reference to normal function and without empirical evidence from prior cases. The causal field is defined by the normal, physical anatomy of the object of diagnosis.

In the medical case, correction depends on introduction of a change, e.g., by medication, having a corrective effect. In this case, the diagnostic field may be the same as for compensatory search, i.e., the functional structure of the system in question. Search is aimed at finding an element or parameter in the functional structure which is sensitive to one of the means available. That is, the causal field is strongly influenced by the diagnostician's medical "tool box."

In the typical case of technical repair or medical surgery in response to physical damage, the diagnostic target is to locate the faulty component or organ and, locally, to replace or mend it. This means that reference to the *location* of the root-cause of a disturbance is the aim of the diagnostic search, i.e., the location of the particular faulty organ or component which is the origin of the abnormal functional condition. In this case, topographic reference to the location of the disturbance must be drawn from the observations. Such topographic reference can be drawn from observations in basically two different ways:

One is to draw a reference from the location of the source of the observations (topographic diagnosis). Another is to infer a topographic reference from the functional significance of the content of the observation, i.e., the pattern of symptoms found (symptomatic diagnosis). The repertoire of diagnostic strategies applied by skilled technicians for locating faults in technical systems have been identified from analysis of verbal protocols. They illustrates the basically different structure and resource requirements of strategies applicable to one particular diagnostic task (see Rasmussen and Jensen, 1974).

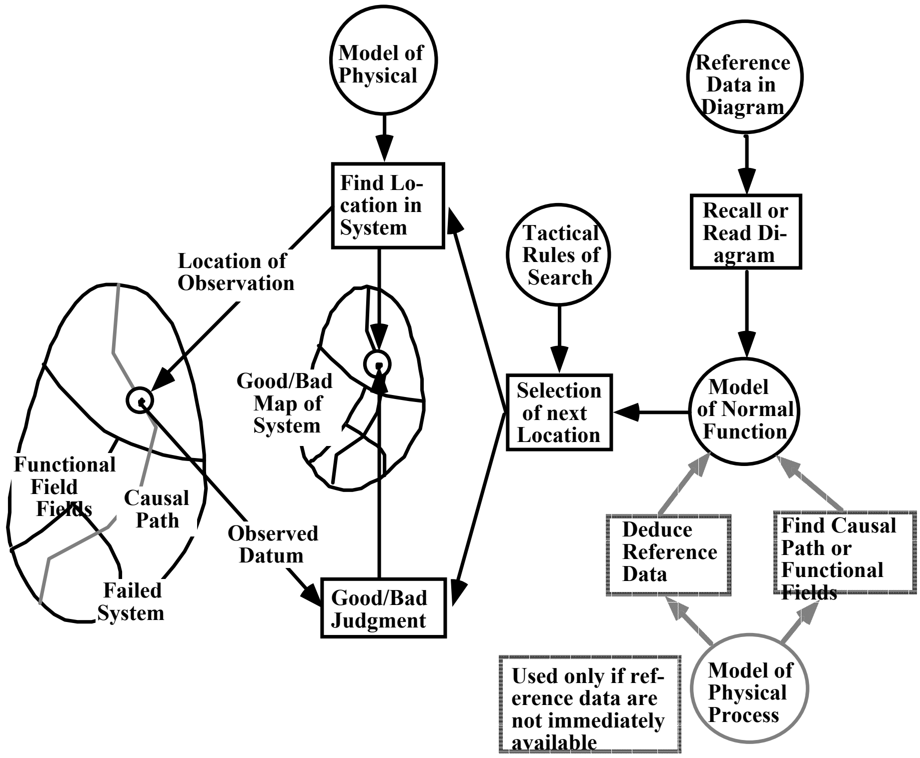

Figure 3. The topographic search is performed by a good/bad mapping of the system through which the the potentially "bad" field is gradually narrowed down until the location of the change is determined with sufficient resolution to allow selection of an appropriate action. The search depends on a map of the system that gives information on the location of potential sources of information for which reference information is available for judgments. The diagnostic field is a model that identifies the potential sources of observations relative to the topology of the physical system itself.

Topographic diagnosis. The search for the origin of a fault can be performed directly in the system itself. That is, observations are made at various locations in the system, the observations are judged to be good or bad with reference to a template representing the normal functional state and the possible location of the fault is judged from the *location* of the observations. The topographic search is a kind of good-bad mapping of the system (see figure 3). The diagnostic field in this case is a topographic map of the location of functional elements within the physical anatomy of the diagnostic object together with a set of "*normal* state" reference templates given for suitably located observation points. The region in which the fault is located can be systematically narrowed down by suitable tactical search rules. For instance, a frequently used fault finding strategy in electronics is the "half-split" heuristic. If the signal is normal at the input of a path, but missing at the output, then the most information economic search tactic will be will be a progressive "split-in-half" and test of the path, i.e., to zoom-in on the location by always making the next observation at the mid point of that part of the path in which the signal disappears).

Also in this case, the diagnostic field is independent of empirical evidence from prior cases. The stop-rule for termination of decomposition and search is very pragmatically determined. There is no need to seek beyond the level of decomposition at which parts are can be replaced as standard units, i.e., the stop rule is given by the spare parts and/or the tools available.

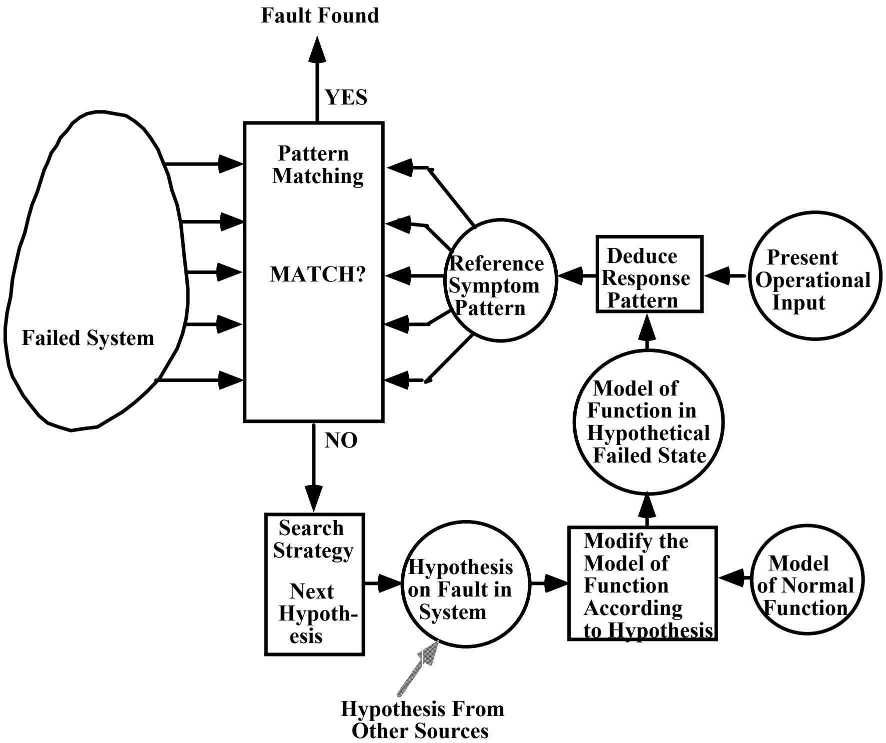

Figure 4. Search by hypothesis and test depends on comparison of the observed symptom pattern and of a pattern deduced by means of a model of normal system function modified according to the current hypothesis.

Search by hypothesis and test. While the topographic strategy derives reference to the location of the fault from the *location* of the observations, search by hypothesis and test derives such reference from the information content in a set of observations. This involves functional inference based on a symptom pattern. The search is based on deduction of the effect of a hypothetical fault by means of a model of the normal functional constitution of the system. Diagnosis involves generation of suitable hypothesis (frequently found by initial use of on of the empirically based strategies) and a verification by deduction of the propagation of the functional aberrations from the hypothetically faulty part to the observed features (see figure 4).

The causal field for deduction of symptoms in this case is a representation of the normal functional and causal structure of the system which can be used to trace the propagation of the effects of hypothetical causes of failure.

3.1.4 Analysis for Identification of Persons to Charge

In order to allocate responsibility and judge the need for retaliation, a variationist approach will normally be used to locate a responsible person. The search will take place up-steam along the unusual course of events including erroneous human activities. That is, aberrations will be identified with reference to the usual or intended state of affairs. The search will be very similar to that applied for understanding the case, but a particular stop-rule will be used to terminate search, i.e., the search will stop when a person is found who made an error and at the same time, 'was in power of control' of his acts. The very nature of the causal explanation will focus attention on people directly and dynamically involved in the flow of abnormal events. This is unfortunate because they can very well be in a situation where they do not have the 'power of control.' Traditionally, a person is not considered in power of control if physically forced by another person or when subject to disorders such as e.g., epileptic attacks. In such cases, acts are involuntary (Fitzgerald, 1961; Feinberg, 1965), from a judgement based on physical or physiological factors. It is, however, a question as to whether psychological factors also should be taken into account when judging 'power of control.' Inadequate response of operators to unfamiliar events depends very much on the conditioning taking place during normal work. This problem also raises the question of the nature of human error. The behaviour of operators is conditioned by the conscious decisions made by work planners or managers who will be more 'in power of control' than an operator in the dynamic flow of events. This means, that the causal field of diagnosis for charging people should be influenced by or include the features of the cognitive control of the people involved in the actual situation.

3.2. Strategies Involving Instantiation of General Causal Relations

When the internal functional structure is badly known, the variationist approach described in the previous sections cannot be applied, and then diagnosis must be based on a search backward through a hierarchically organized body of empirical evidence from prior cases. The search space will be represented by a kind of decision tree which represents the hierarchical structure of empirical categories. The specific causal complex which is actually considered for a given case cannot include all possible branches of the total causal network. A botanical field guide is an example of such a complete, analytical reference case. A complex, medical reference case for diagnostic identification of complications in anaesthesia is presented by Hovde and Rizzi (1991). The causal field considered will evolve during the diagnostic process (this has also been noted by Rizzi, 1991). The selective use of the total empirical causal tree is guided by the tacit knowledge of the analyst which, for the expert diagnostician, supports a very effective "first guess" (see Pedersen and Rasmussen, 1991).

The causal field in which the search is done, normally is based stored, empirically established causal relationships. The degree of condensing and telescoping of the empirical evidence depend on the particular case and the level of expertise of the diagnostician. In frequent cases, familiar to a diagnostician, an empirical diagnosis can be based on a direct recognition of the symptom pattern in terms of the appropriate act. In this case, the causal chain has been "condensed" to only one link. For more infrequent or complex cases, Mackie's "telescoping", i.e., a more detailed decomposition of the causal connections, can become necessary. In this connection, controlled experiments may be necessary. In such cases, simulation can be applied for generating operating instructions for industrial plants or controlled medical experiments can be used to establish the properties and rules for the use of appropriate drugs.

This kind of diagnosis depends on symptomatic search, i.e., the abnormal state of the system is represented by a set of observations, symptom pattern, which is used as a search template used to find a matching set in a library of symptoms related to previously experienced abnormal system conditions. The strategies which are used for different diagnostic purposes, such as compensation or correction, are similar, while the diagnostic fields will vary, as it is discussed in the subsequent sections.

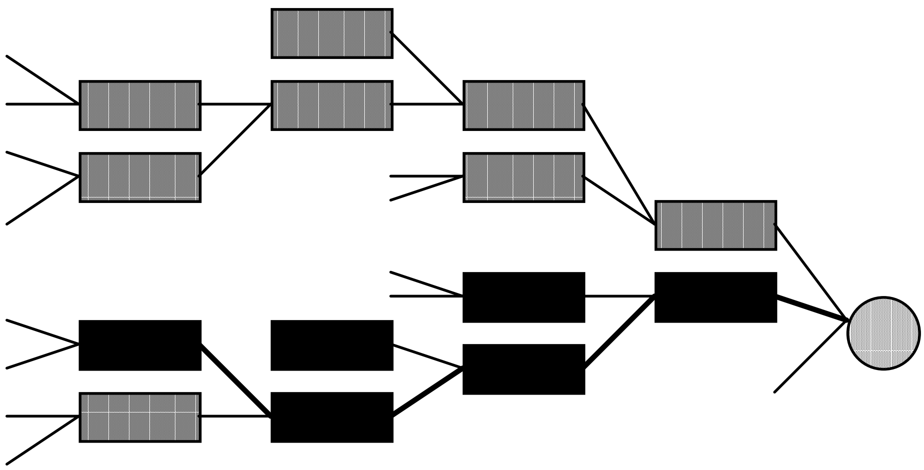

Figure 5 serves to illustrate that in a particular diagnostic session, the causal tree considered emerges from a more complex tree of possible branches which are, however, not activated in that particular case. The tacit knowledge of the analyst focuses the attention on the relevant part of the total causal network. This selective focus of a first guess is the hallmark of an expert diagnostician.

3.2.1 Recognition

Frequent cases can be recognized directly when their symptom patterns are met in their familiar context. The categories of abnormal conditions, represented by a particular symptom pattern can empirically be labelled directly in terms of its cause, the location of disturbed function, or its proper cure (figure 6). No coherent or explicit diagnostic field can be identified, memory search is done with a patterns template without guidance from the semantic connotation of the pattern. The diagnostic field in this case is the general, but subjective, episodic pool of empirical evidence available to the diagnostician.

The recognition strategy includes what Pejtersen (1979) calls the empirical strategy applied by skilled librarians: the population of users is divided into stereotype classes associated with certain categories of book content. For instance, elderly ladies with grey hair and glasses are very likely to be offered family novels without any interrogation of their needs. Similarly, medical doctors very likely have related classes of patients and treatment and the initial associative guess will determine the diagnostic field activated for more conscious verification of a diagnosis by other strategies. This complementary relationship between intuitive hypotheses and deductive verification has been discussed in detail for mathematicians by Poincaré and Hadamard (see Hadamard, 1945)

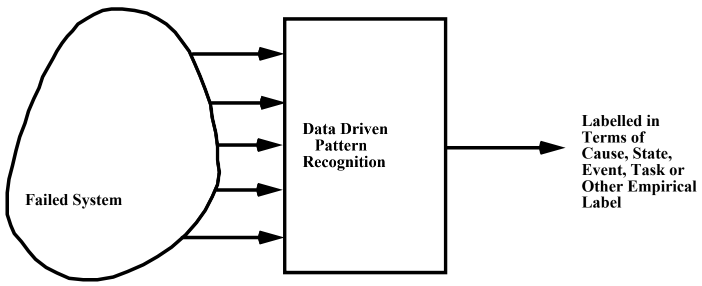

Figure 6. Diagnosis by recognition depends on direct association from the observed pattern to a class of abnormal states, labelled inductively in terms of cause, state, corrective task, etc

3.2.2 Search in a Decision Tree

Less familiar cases requires a search through a diagnostic field which represents a hierarchical ordering of the categories of diagnostic experience (figure 7). The result of this search is the identification of that particular subset which constitutes the "causal complex" (Wulff and Pedersen, 1989) characterizing the actual case. The selection of categories to include in the causal complex will typically be unsystematic, it will be guided by a changing perception of relevant action alternatives along the path, and categories will be labelled pragmatically in terms of the origin, source, type, or location of the disturbance or its effects or of a possible relief.

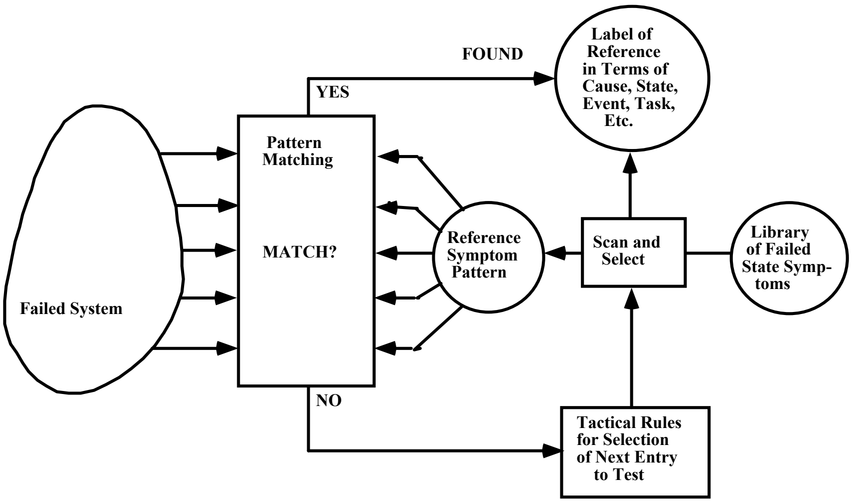

Figure 7. Search by decision table entry. Search in a library of cases by matching symptom patterns to previously observed patterns or patterns generated by simulation or functional analysis.

In a body of empirical, causal relations, the labelling of categories and relations is based on correlation and labels can be related to very different conceptual domains. A set of symptoms, for instance, can be labelled in terms of its cause, the failed part or function, its location, or the appropriate corrective action. Therefore, as mentioned, the empirical, diagnostic strategies applied are largely independent of the purpose while, however, the causal field considered will be influenced by the problem at hand.

3.2.3 Analysis for Compensation

The objective of the search is to identify among a relevant set of system functions which can be acutely endangered, that function which should attended. Then, the nature of the state of the system should be identified with reference to the possible compensating acts. This implies a search in a diagnostic field in which the labels at the branching nodes will represent different concepts, such as vital system functions, disturbed functions, and relevant, alternative compensatory actions.

In other words, the causal field represents vital functions and the causal network connecting the state of such functions to parts or parameters, sensitive to possible compensatory actions.

3.2.4 Analysis for Correction

In general, expert diagnosticians such as e.g., skilled medical doctors and process operators, who have been faced with particular diagnostic objects through a long period of time will base diagnostic judgment on operating experience even when analytical, variationist diagnosis is possible. This is an immediate consequence of a tendency to follow the path of least resistance and, frequently, to save time in a critical situation.

The diagnostic field will represent the diagnostician's pool of experience from prior cases with no systematic structure. It is, however, possible to choose a idealized, normative order which can support teaching of novices. This normative strategy, therefore, is the one found in medical textbooks. The categories will be defined empirically with reference to disease categories related to targets of intervention (see figure 8). The causality implicit in the representation *reflects logic necessity, not temporally ordered cause-effect relations.*

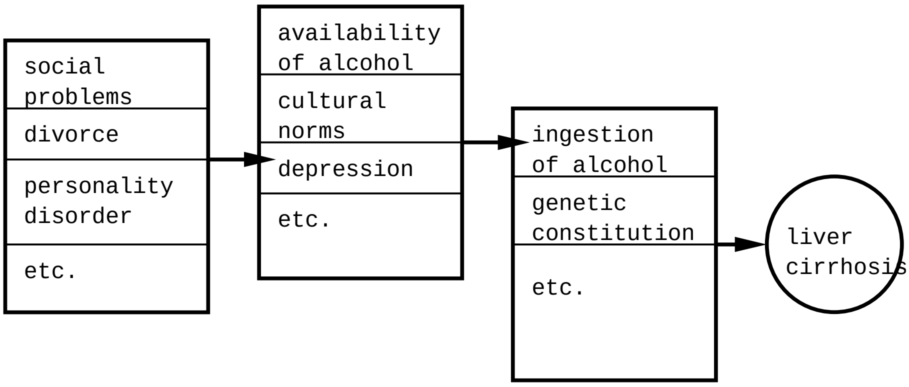

Figure 8. The doctor who treated the patient was in no doubt that the liver disease was caused by alcoholism, as the ingestion of that amount of alcohol may be regarded as a sufficient cause of liver damage. But it is also known that the extent of the damage and the cause of the disease is to some extent determined by the patient's genetic constitution. If the patient's ingestion of alcohol had been less extreme or he had had a stronger genetic constitution he might not have developed cirrhosis of the liver. Furthermore, many other processes may lead to cirrhosis of the liver, as, for instance, various kinds of virus infection, metabolic defects, etc. (Adopted from Pedersen and Rasmussen, 1991)

3.3. Judgment Concerned with Generalization

In order to prevent a repetition of a case, another kind of diagnostic judgement is necessary. It is necessary to infer from the particular case, a change in the system or its environmental conditions which will serve to decrease the likelihood of similar, future cases. For this purpose, the causal field will be analyzed to identify an element which is sensitive to change in a way which will will serve to break the flow in future repetitions of similar cases. This implies identification of the actual causal chain in the proper temporal order, see figure 9.

The search for cures presents some basic problems. Frequently, prevention will be associated with prevention of events perceived to be 'root causes.' In general, however, the effects of the accidental course of events in a particular case could have been avoided if any link in the causal tree or its conditioning side branches had been broken or blocked prior to that particular occurrence. It is, therefore, very easy to suggest many possible counter measures from the analysis of a single case. The danger is, however, that most of these are particular ad-hoc measures, only effective in the singular case. Careful generalization from the observations in a singular case is therefore necessary.

In addition, explanatory descriptions of particular cases are, as mentioned, focused on unusual events. However, a causal path can be broken by changing also the normal events and functions involved. For prevention of future repetitions, therefore, a decomposition of the flow of events should include also the normal activities, not only on unusual events.

3.3.1 Modes of Generalization

Basically different approaches to generalization are pertinent for different kind of systems, depending on, whether their functional structure is stable and accessible to analysis. In the subsequent sections, a distinction is made between the approaches taken to generalization from accidents, depending on the stability of the system and the degree to which it is accessible to analysis.

3.3.2 Physically Structured, Stable Systems: Functional Generalization

One important class of systems having a stable functional structure accessible to functional analysis includes technical systems which are designed for some particular purpose. Such systems are particular exemplars of a general, conceptual design. In such cases, generalization involves simply referring back from a particular accidental chain of events to the general design intention. Prevention of the repetition of a particular accident involves reconsideration of the functional design. An analysis of the course of accidental events serve to establish the propagation of events through the functional structure. Consistent generalization can then be based on a probabilistic reliability and safety analysis including a sensitivity analysis with respect to several potential forms of improvements, such as improved quality of components, introduction of redundancy, protective functions against loss of control of major mass and energy flows, etc.

In other words, the causal analysis serves to identify the propagation of accidental changes in the normal functional structure of the system, as designed, and generalization involves a reconsideration of the conceptual design which is materialized in the particular system. The ultimate causal field is established by the normal, physical anatomy of the system. The causal connections necessary to trace propagation of changes in this structure is deduced from a the laws governing the behaviour of the physical components. In other words, the causal field is generated for each particular case from basic laws of physics.

3.3.3 Nominally Structured Systems: Variationist Generalization

An important class of systems for which generalization from observation of unacceptable conditions is important includes social organizations such as operating organizations of major technical systems. Such organization have a kind of "designed" functional structure and an established pseudo-stable procedural practice. For such systems, no stable laws of physics can be the ultimate source of causal relations and causal analysis of the propagation of accidental events in an organization is typically done in terms of aberrations from normal procedure, i.e., by the variationist strategy. In this case, generalization from a record of an accidental chain presupposes a careful analysis of normal, functional relations. In this way, the causal field underlying search for causal connections which are sensitive to improvement will be the normal, causal relationships of system function. The particular case will be a variation tree displaying the propagation of aberrations.

One basic restriction of generalization from such a causal analysis is that it presupposes a stable causal structure of the system. The causal tree as found by an accident analysis (see figure 9) is only a record of one singular case. For nominally structured systems, it is not a model of the involved relational structure. For instance, a representation of a causal chain generally does not take into account closed loops of interaction among events and conditions at a higher level of individual and organizational adaptation.

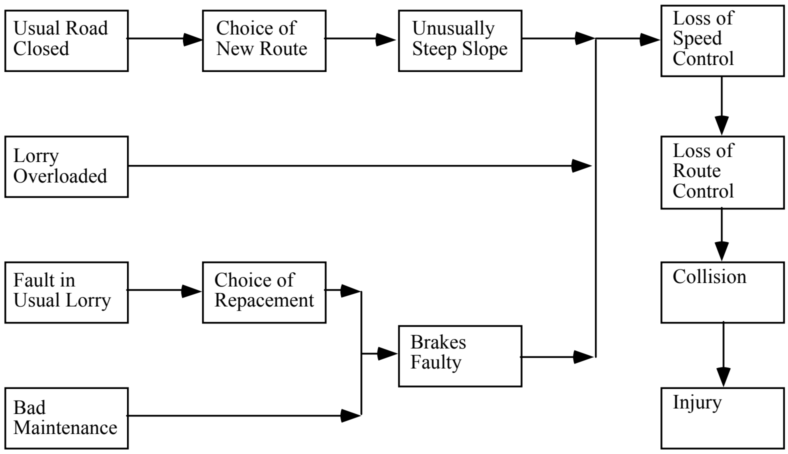

Figure 9 illustrates the variationist approach to analysis of an accidental course of events. Nearly all the events included are labelled with reference to a change of a normal state of affairs or a normal work practice. (Adopted from Leplat and Rasmussen, 1984).

In systems including feedback loops (figure 10), identification of "improvements" in causal terms may be unreliable due to the feedback compensation. When radar was introduced to increase safety at sea, the result was not increased safety but more efficient transportation under bad weather conditions. Will anti-blocking car brakes increase safety or give more efficient transport together with more abrupt and irreversible boundaries to loss of control? (Rasmussen, 1990c). A feedback path will, in many cases, depend on purposive human activities and be opaque for post event analysis. However, it will be difficult, even if the path is recognized, to determine whether causal arguments in a closed loop constitute a convergent or divergent series. That is the reason why the instability of Watt's steam engine regulator was only understood when Maxwell replaced causal analysis by differential equations.

This makes reliable generalization by a variationist strategy difficult. Therefore, a functional approach to generalization will ultimately be necessary also for socio-technical systems. For this purpose, a reliable, predictive model of human adaptation is required describing the involved feedback mechanisms together with the performance criteria and value systems of the involved actors.

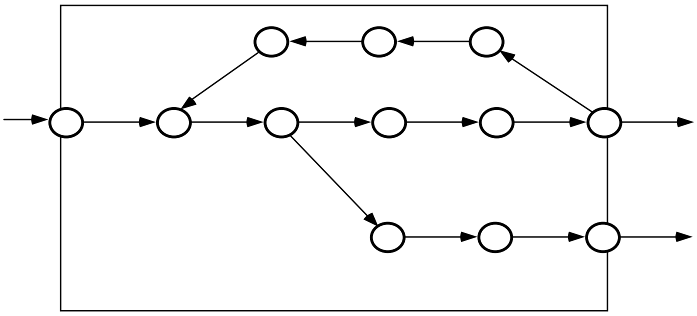

Figure 10. In systems including feedback loops, identification of "improvements" in terms of causal chains to break or events to eliminate, in order to prevent future repetitions may be unreliable due to the feedback compensation.

3.3.4 Unstructured Systems: Empirical Generalization

Many systems have very unstable functional structures (e.g., work conditions at a construction site), they are not transparent to functional analysis with a well defined design state (e.g., human health), or reliable models of normal function cannot be established (e.g., performance in complex organizations). In such cases. generalization must be based on comparison of cases across systems and/or through time by statistical and epidemiological analysis.

In such analyses, generalization serves to identify therapeutic means which each are effective for many of the singular cases which constitute the empirical evidence. Empirical generalization in this case implies a super-position of a number of particular cases in order to derive super-ordinate classes of causal connections. This is normally done in medicine and work safety by epidemiological analysis of cases of diseases and work accidents. Then, generalization can be done at any level of decomposition and aggregation (condensing or telescoping, to speak with Mackie). The causal connections identified by epidemiological analysis are ordered in a hierarchical decision tree which constitutes the reference case, from which the particular "causal complex" used for decision making in the particular case is drawn. In contrast to the functional strategy, which is based on *causality defined by functional relations derived from laws of nature*, the empirical strategy relies on *causality defined by class membership and logical necessity*.

There is a tendency in the historical development, that empirical generalization is replaced by functional generalization. For cholera, for instance, treatment was based on empirical observations of the positive influence of isolation of people from crowded and badly sanitized town environments until the theory of bacterial infection was established. Then this, law based generalization took over for planning of the same kind of treatment: isolation. Later, the new generalization led to improved medication.

4. Diagnostic Fields in Ideal Strategies

It is by now clear that the context in which diagnostic reasoning takes place, i.e., the diagnostic field, in the various idealized strategies is of a very different nature. In search by *recognition*, the field is only implicitly defined in terms of the pool of episodic experience of the diagnostician. In *decision table search*, the field emerges as a decision tree unfolding as the search progresses in the experience of the diagnostician, i.e., the potentially interesting branches together with the attributes to look for are determined by the immediate context. The causal relations implied in the tree can be determined inductively (typical for medicine) or deduced from a model of the functional structure of the system (as typical for design of operating instructions for technical systems). For the expert, in technical process control as well as in patient treatment, the diagnostic tree will be derived inductively from experience. In diagnosis by *hypothesis_and test*, the diagnostic field is formed by the functional structure of the system serving as a basis of deduction of symptoms from a postulated cause. In *topographic search* for the location of the source of the symptoms, the diagnostic field is a representation of the physical anatomy of the system in which a good-bad mapping is made.

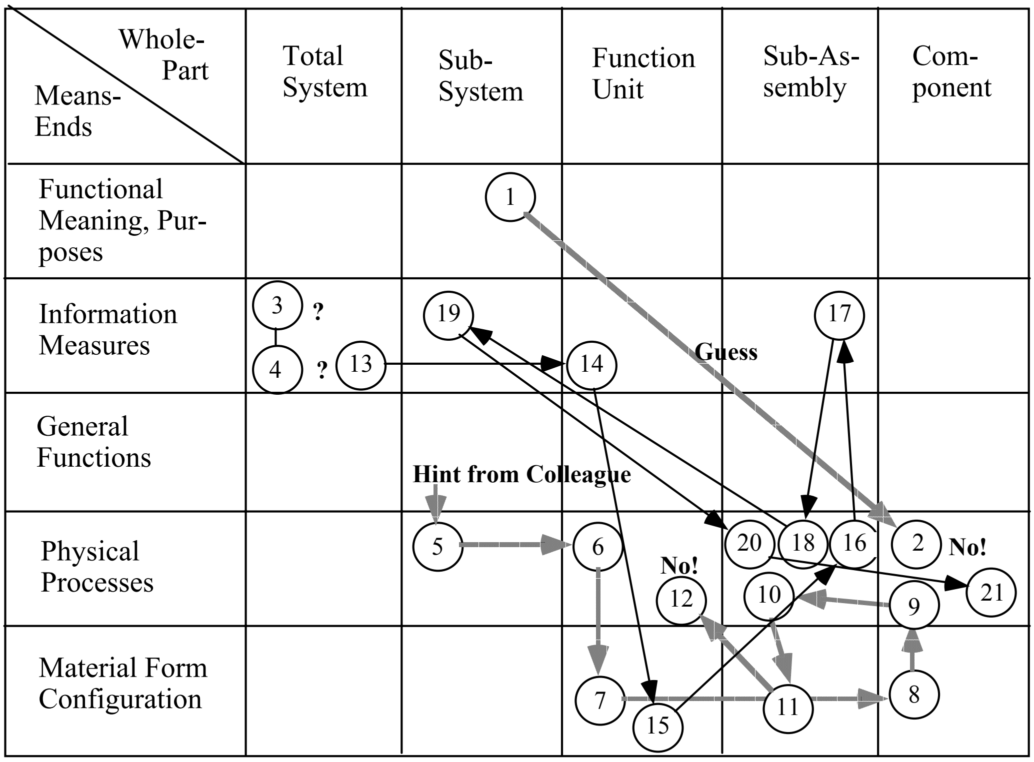

Figure 11 shows the trajectory in the work space taken by a computer maintenance engineer. He starts (A) by guessing a familiar fault from mere recognition. When proved wrong, he gets some hints from a colleague's experience the day before and (B) continues from episodic evidence without success. Finally, he (C) enters a sequence composed of pieces of strategies from topograhic and hypothetical search.

Some guidance is needed for choice of the set of elements to categorize, the level and extent of discretization. Or, in other words, a diagnostic field of a suitable resolution must be chosen. The general diagnostic situation and the purpose of the diagnosis serves to bring attention to a context within which the purpose adequately defines the elements to consider. Diagnosis is the identification of the state of affairs in the world, which makes it possible to act in pursuit of a particular goal. Therefore, the options for action towards that goal also serves to structure the diagnostic field to consider.

NATURAL STRATEGIES

The discussion of the idealized strategies serves to formalize the processes, information requirements, and the cognitive load on the diagnostician for different approaches to diagnosis. The "natural strategies" applied in actual work situations, however, will involve very frequent shifts among such idealized strategies for several different reasons.

This formulation of natural decision making brings it close to Hammond's (1984) conception of quasi-rational thinking involving both rational and intuitive judgment strategies (Hammond, 1984), with the rational part taking care of cue analysis of rule-based behavior and the functional analysis of knowledge-based reasoning.

One reason to shift between strategies is their very different resource requirements with respect to time taken, information and background information necessary, etc. Shifts in strategy, consequently will be a very effective way to circumvent difficulties along the path. An example of the shifts in strategies is shown in figure 11 which shows the trajectory in the work space taken by a computer maintenance engineer. He starts (A) by guessing a familiar fault from mere recognition. When proved wrong, he gets some hints from a colleague's experience the day before and (B) continues from episodic evidence without success. Finally, he (C) enters a sequence composed of pieces of strategies from topograhic and hypothetical search.

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Another reason for shift of strategy in a particular work scenario will be that the diagnostic objective will change during a session. Initially a medical doctor or a process operator will be concerned with the question whether he is confronted with a need for rapid compensatory action, i.e., he is concerned with the potential consequence of the present state. Next, he will be concerned with the choice of a function to stabilize. Then he will be concerned with the correction of the present abnormality and, finally, he may be concerned with prevention of a repetition. This means that a diagnostician will shift strategies also in response to changing priorities of different objectives. He will, of course, not start diagnosis from scratch for each objective and a complex transfer of results will take place between the phases applying the different strategies.

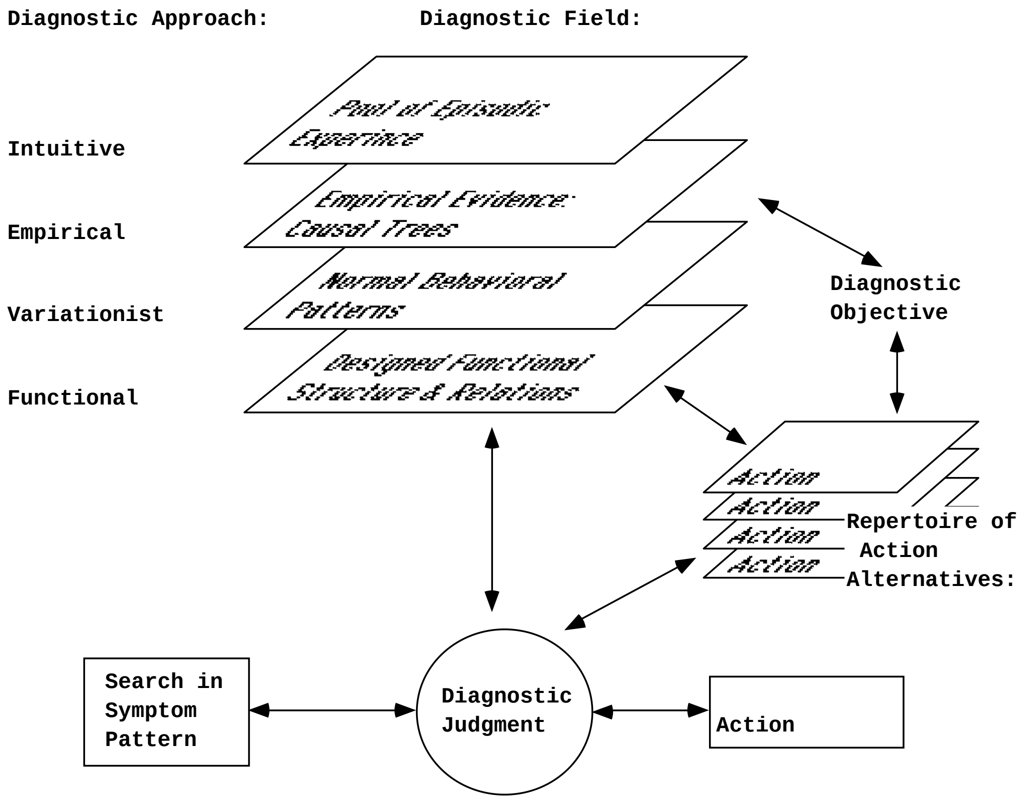

Figure 12 illustrates the elements of a "natural diagnostic process." The approach taken and the diagnostic field activated will depend on the immediate circumstances, including aspects such as demand/resource conflicts, cues from prior experience, the perceived action alternatives, etc. Consequently, diagnostic fields of very different nature will be used, corresponding to the frequent shifts in the diagnostic strategy applied. A basic circularity is found between the diagnostic objective, the interpretation of observations depending on the activated diagnostic field and perceived repertoire of action alternatives for the case given. The process, therefore, will have the character of zooming-in from an intuitive initial guess.

5. CONCLUSION

A couple of important implications of this nature of natural strategies should be mentioned here. One is, that several "diagnostic fields" will be accessed during a particular scenario, the diagnostician will work on the background of a "multi-dimensional intuition," switching between different strategies by transitions which are cued by observed evidence which presents "affordance" (Gibson, 1966) with respect to one of the latent causal or diagnostic fields.

Another important observation is, that modelling and simulation of diagnostic performance outside controlled laboratory environments will have to take into account all the available strategies. An important modelling problem will, in particular, be to identify the performance criteria and the cues in the subtle work setting which control the transitions among strategies.

Finally, it must be realized in design of decision support system, that such systems should support all the effective idealized strategies, or else the diagnostician can be severely constrained in shifts among strategies which could serve the resolution of local demand-resource conflicts.

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