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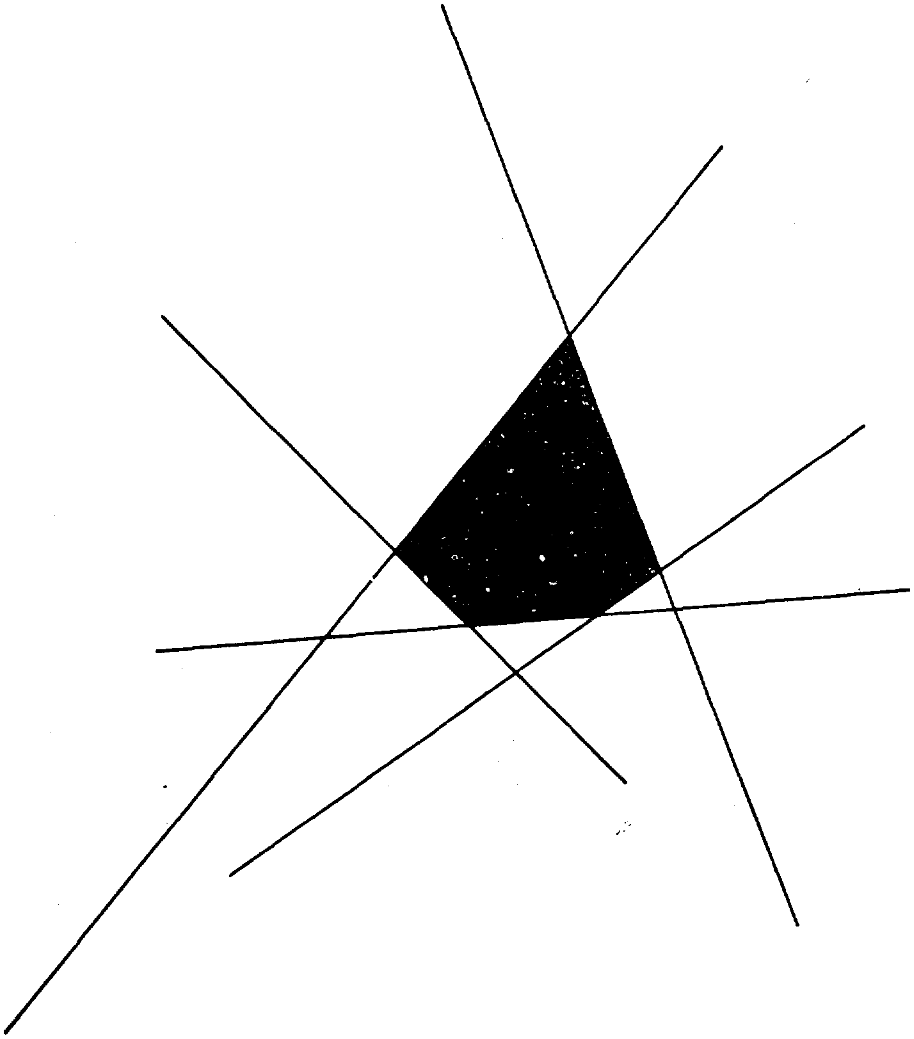
by
STUART E. DREYFUS



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ABSTRACT

Possible limitations on the successful formal modeling of human expertise can only be identified if the evolving thought processes involved in acquiring expertise are understood. This paper presents a 5-stage description of the human skill-acquisition process, applies it to the skill of business management, and draws conclusions about potential uses and abuses of formal modeling.

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I. INTRODUCTION

For a discipline to grow and prosper, its practitioners must recognize not only its potential contributions, but also its limitations. To seek the unattainable is a misguided allocation of resources, at best, and is ultimately a sure path to discredit and disuse. I thus regard my investigation of the limitations of formal modeling reported below, not as an attack upon my professional field, but as an attempt to redirect its thinking in such a way as to improve its practice and facilitate its development.

While my discipline, variously called management science, operations research, systems analysis etc., may well be growing, it is by no means clear that it is prospering. A study by McKinsey and Company of eight management attributes that are common to the 37 companies which are often used as examples of well-run organizations, emphasizes that none of the attributes depend on modern management tools such as are provided by management scientists, [1]. A recent article in The Wall Street Journal by management consultant Thomas Peters calls formal planning a fetish [2]. A 1981 article in the Sunday New York Times Magazine on the problem of the recent decline in quality of America's business management [3] cites over-reliance on quantitative analysis as part of its cause. It quotes UCLA management professor William Ouchi that "managers are often heard to complain that they feel powerless to exercise their judgment in the face of quantitative analysis, computer models and numbers, numbers, numbers," and Harvard Business School professor Robert Hayes as saying "Look, I'll admit it. I was one of the guys teaching all the quantitative methods with such vigor. I was part of the problem." Earlier, a study by Mintzberg was critical of analytic planning which, he reported, had had little impact on how top management functions [4]. To diminish such criticisms and increase the impact of their recommendations, management scientists must avoid complacency, and one way to do this is to understand better the true skill of management and the differences between it and the formal representation of it in a model. While several authors have contrasted the analytic reasoning process of the management scientist with the intuitive thought process of the manager [4], [5], none has examined when, and why, one process is to be preferred to the other or to what extent intuitive understanding can be captured in a formal model. In this paper I shall investigate the development of the intuitive thought process of the expert manager in detail, showing how it evolves from, and transcends, analytic thought. I thereby establish inherent limitations on analytic modeling and indicate both its proper use and potential abuse. To the probable dismay of analytic modelers, it turns out that the most critical factor in establishing the boundary between proper use and abuse of models is itself not objectively or quantifiably specifiable--it is the extent of the manager's sense of familiarity with, and understanding of, the problematic situation in which he finds himself.

Only rarely can problems and opportunities in the business world be *objectively* recognized and defined. Those that can are generally technological problems, or problems calling for an operating manager's logical deduction of the cause of some undesired event. This sort of problem solving, the subject of many training programs such as those of Kepner-Tregoe, Inc. [6], is not what concerns us here. Nor are we concerned with certain fairly objectively defined problems such as petroleum blending, insofar as these problems concern only clearly defined physical constraints and an objectively specifiable cost criterion. Objectively defined problems are clearly within the proper domain of systematic analysis. We are interested instead in unstructured situations. Sometimes, these involve decisions of major importance, such as those concerning diversification and plant expansion, major capital expenditures, selection of key executives, setting of corporate policy, establishment of organizational structure, etc., which, sexists say, separate the men from the boys. Other unstructured situations involve operating decisions at lower levels. A plant manager must choose among newly developed tools and procedures, a logistic planner must adapt to transportation equipment breakdown, a salesman must budget his limited time, etc. For all of these unstructured problematic situations, both major and minor, no objectively defined set of facts and factors completely characterizes the problem setting, permissible actions and the goal of the activity. While in each of the above activities certain objective facts and events are clearly relevant, many others may be seen as either crucial or as insignificant depending upon the decision-maker's interpretation of the situation. Yet other events may critically affect a manager's behavior without his conscious awareness even of their presence. Such is the nature of unstructured situations, and it is these situations, not the rare objectively structured ones, that pervade the business world.

Understanding through interpretation is an essential activity of policy makers and of business managers. Sometimes the understanding of experts is the basis of prediction, generally used to assist the planning of others. Typical types of predictions concerning unstructured situations include: forecasts of economic conditions or of energy usage, and predictions of business or political trends.

Besides providing predictions based on situational understanding, a second essential role of managers is the determination of a resolution when the situation is perceived to require action. In this case, one cannot divorce understanding from decision. While operations research has had much to say about prediction and decision on the basis of models supposedly representing situational understanding, little has been said about the relation between the actual understanding of the experienced manager and that represented in the models.

It is taken for granted that mathematical models involve abstractions and simplifications. Most members of the Operations Research community believe, however, that although their formal models of experienced and expert managerial understanding are only approximations, the power of mathematics and computation will more than compensate for the simplifications, and prediction will be enhanced or decision-making improved. A recent paper by Howard [7] not only articulates this view and presents many arguments alleged to support it, but specifically criticizes my contrary perspective. Since my position is necessarily stated by Howard without context, and is quoted from an unpublished 1977 manuscript, it seems mandatory at this time that I both make my concerns public, defend them, and question the validity of many of the arguments presented by Howard.

I shall argue that formal models do not represent abstractions and simplifications of expert understanding, but rather that a model represents a type of understanding that is typical of inexperienced beginners and that this type of understanding is, after sufficient real-world experience, supplanted by a much superior mode of human situational understanding totally different from that represented by a model. Consequently, there is good reason to distrust a formal model of expert understanding. While I believe that an expert possessing innate ability can perform better than any formal model when dealing with unstructured situations, whether they concern high-level strategic planning or operational decision-making at as low a level as routine equipment replacement or spare-part inventory decisions, I do not oppose formal modeling at the operational level. I see such formal models as steps toward routinization rather than optimization, and as such they are well-justified since they allow human decision-making expertise to be directed toward more important problems.

The best information on the nature of experience-based human understanding derives from careful description of actual real-world skill-acquisition experiences. Since we have all developed, through training and experience, innumerable real-world skills (such as social skills for conversing and partner choosing, professional skills such as those used in business decision-making, shopping skills, automobile driving skills, chess, poker or tennis game-playing skills, foreign language speaking skills, etc.) our recollections of how we perceived each of these task environments as novices, and how our understanding evolved as our skill developed, provide valuable insight. What concerns us is *not* what specific facts and rules, if any, one learns from experience and how these produce particular skillful behavior, for introspection has been shown to be untrustworthy in this effort [8], but rather the changing nature of mental activity during skill acquisition. We shall ask such questions as: When is decision-making abstract and analytical and when concrete and intuitive? When is it conscious and explainable and when unconscious and mysterious? When is it slow and laborious and when fast and easy?

Less trustworthy than personal recollection of skill-learning experiences, but helpful, is the careful observation of subjects as they undergo real-world learning. Here again, reports by subjects on *what* they have learned are notoriously unreliable, but the changing nature of their mental activity can sometimes be described.

Since we are interested here principally in the real-world skill of the experienced expert, the countless controlled experiments performed in psychology laboratories in which subjects perform unfamiliar tasks are of no relevance.

While it may sound heretical in this scientific era, we ask the reader to evaluate our conception of skill acquisition by personally checking our descriptions that follow against his own experiences. Only if our descriptions seem intuitively valid do we expect the reader to accept our conclusions. The executive decision-maker should mentally apply our phenomenology to those areas in which he has personal expertise. The experienced mathematical modeler should ask whether we have in any way illuminated the process through which he acquired his modeling skill. The Operations Research practitioner should refrain from testing our model against his *theoretical conception* of the learning and thinking process of the business decision-maker with whom he works.

We shall illustrate our five-stage developmental model of skill acquisition by means of personally meaningful examples concerning automobile driving and chess playing. While neither of these example areas exactly duplicate the managerial environment, it seems reasonable to conclude that any pattern that proves discernable in both of these diverse areas also holds for business decision-making. Driving, like business, occurs in a stochastic environment with opportunities as well as risks. While chess, unlike business, is a deterministic microworld completely describable by isolated elements of objective data (the board position of each piece) and by objective strict rules of allowable board transformation, strong players *experience* the game as a rich panorama of tensions, opportunities, risks, etc. just as managers experience their own domain of expertise. George Steiner asserts in [9] that the great chess player internalizes, not squares with pieces on them, but rather a very special sense of "fields of force," a cluster of potential actions, a space of and for evolving events. (Because of the complete specifiability of the current position and all possible future situations in terms of isolable objective data, computer programs currently use brute-force computational speed and accuracy to play chess quite well, but this is *not* how human masters approach the game and it is human skillful behavior that concerns us here. Due to this unnatural objectivity of chess, one cannot draw any optimistic conclusions from the success of chess-playing computer programs about computational models and methods applied to non-objectively specifiable real-world problems.) The relevance of chess understanding to business judgment might be questioned because in chess, unlike business, the decision-maker knows his situation (position) with certainty. Strong chess players, however, have little trouble adjusting their thought processes to the game of kriegspiel, a variation on chess in which each player does not see his opponent's position and must infer it from information about the chess legality of attempted moves.

Besides illustrating our skill-acquisition model with examples from the above two areas, at least one of which most likely represents a domain of reader experience and skill, we shall try our hand at illustration by means of a business skill, marketing management. Not being personally experienced in this area, we can only speculate. The amount of verisimilitude that experienced marketing decision-makers find in our description will be a test of our theory.

After a brief statement in Section II of our general conception of the process of skill acquisition, in Section III we cite evidence supporting our model and contrast our picture with other, more analytical, models. After presenting in Section IV a detailed account of our notion of the mental activities characteristic of an experienced and expert executive decision-maker, we examine in Section V the inherent limitations on the augmentation of these activities through the use of formal modeling.

While it is clearly demonstrable that experience, combined with innate ability, produces a changed perception of the task environment with an accompanying increase in the level of performance in such activities as driving, chess playing, and poker playing, the latter representing decision-making under combined risk and uncertainty, it is more difficult to distinguish luck from skill in managerial decision-making situations. We must therefore take as axiomatic that, like in driving, chess, and poker, the changed perception of the task that comes with experience does, together with innate ability, produce superior managerial decision-makers. Should this assumption be false, and should experienced managers be no more skilled than novices just out of school, with those viewed as best merely being the luckiest, our descriptions of skill acquisition below are irrelevant and our conclusions about inherent limitations on mathematical models unjustified.

Much has been written concerning the quality of human decision-making and prediction. It is an indisputable fact that people are poor "intuitive statisticians" when faced with *artificial* experimental tasks for which, by their very construction, Bayes' Law or other probabilistic calculations are objectively appropriate. However, there is no solid evidence available concerning the quality of human *real-world* decision-making or prediction in probabilistic situations because real situations are nonreplicable and single outcomes are never definitive when chance events influence the result. Winkler and Murphy [10] have noted that laboratory experiments, often using either successive coin flipping or a bookbag-and-poker-chip paradigm with conditional independence of trials and assumed stationarity, involve abilities completely different from those taught by the real-world experience of seeking patterns in dependent, nonstationary events. Hence, poor performance on artificial laboratory experiments can even be viewed as the product of misapplied experience-based real-world pattern recognition proficiency. The coin tossing experiment and the investigation of medical probabilistic reasoning cited by Howard [11], as well as most of the experiments that led Slovic et al. to their negative conclusion that is quoted by Howard [12], fall into this category.

Furthermore, almost all of the field experiments conducted thus far that are cited as evidence for poor human predictive performance (see [13] for several such references) suffer flaws. Sometimes what the subject is asked to predict in an experiment is not something that the subject normally observes or explicitly predicts during his real-world skilled performance, even though it may be related to the area of subject expertise. For example, security analysts certainly think about future behavior of stocks, but their work does not require precise probabilistic predictions about performance at the end of 14 days as did the experiment reported in [14]. Frequently, there are real-world incentives for less than accurate prediction. Military intelligence predictions, cost predictions, etc. fall into this category. Perhaps the best current source of studies of systematic bias in expert real-world prediction is weather forecasting, an enterprise which suffers little from either of the above flaws. There, according to [15], we find a notable exception to the systematic biases in prediction that are observed in experiments that are seriously flawed in the ways described above.

At present, it is fatuous to believe that conclusions can be drawn scientifically about the quality of such artful performance as business decision-making or medical diagnosis. As psychologist Fischhoff has pointed out in his review of a book on medical problem solving in which he delineates many of the difficulties plaguing any study of such a complex real-world skill: "In some ways, the study of clinical diagnosis may be as problematic as diagnosis itself" [16]. The same can certainly be said of managerial decision-making. Just as with medical problem solving, extensive careful observation by expert *practioners of the skill*, with tentative, experience-based, extrapolation beyond the hard data, would be illuminating. But simplistic statements such as found in Howard [12] that there is considerable evidence that people are poor real-world decision-makers simply cloud the real issues and, though they may strike the advocate of management science as good advertising material, they might well prove counter-productive if seen by experienced executives as unjustified and insulting.

Even if human real-world decision-making in unstructured, probabilistic, uncertain situations were known not to be good, what concerns us here is 1) whether it improves with experience, and 2) whether models can perform better than experienced professionals. It would be of interest in this respect to compare, in an unstructured repeatable game as psychologically rich as poker, the performance of professional gamblers (not random casino patrons out for thrills) against that of formal mathematical or heuristic models.

There are few examples in the professional literature, which is unfortunately currently dominated by the experimental scientific paradigm, of the sort of introspection and careful observation of skill acquisition that we are advocating. Most notable are the psychologist and chess master deGroot's lifelong study of chess ability [17], the historian of science Kuhn's account of how scientists acquire their understanding of what constitutes acceptable scientific practice [18], and the ethnographer Sudnow's introspective study of the acquisition of improvisational jazz ability [19]. Less detailed than the above, but more relevant, is business school professor Mintzberg's observational studies of business managers [20]. We have drawn heavily upon these accounts as well as upon our personal experiences.

The model that follows was developed jointly with Professor of Philosophy Hubert Dreyfus (University of California at Berkeley) during our recent studies for the Air Force of the development of flying skill. The Air Force, recognizing the importance of intuitive, situational, judgment, has recently adopted a training procedure called "situational emergency training" for pilots of the new high-technology F15 aircraft which stresses training by means of realistic emergency scenarios with maximal student involvement as a replacement for "boldface training" based on memorized strict rules of procedure. A critique of the mechanist position that strict rule-following produces skilled behavior, as well as an analysis of the philosophical assumptions that led to the acceptance of the mechanist view prior to the 20th century, may be found in [21].

II. A FIVE-STAGE DEVELOPMENTAL MODEL OF SKILL ACQUISITION

A. Stage 1: Novice

Normally, the instruction process begins by decomposing the task environment into objective *attributes* which the beginner can recognize without benefit of experience. The beginner is then given *rules* for determining an action on the basis of these attributes. We shall call such attributes, which can be recognized without experience of particular situations in the instructional domain, *nonsituational*.

The student driver is taught to recognize such interpretation-free features as instrument readings and separation distances, and is given rules for when it is safe to enter traffic and at what speed to shift gears. So intent is he upon identifying attributes and calculating responses that in times of stress he may not even hear the instructor's advice. The novice chess player sees pieces as context-free elements and knows a few simple rules such as the rule for computing the material-value of a position by adding up a material value he has learned to assign to each type of piece. A novice, were he unfortunately made responsible for marketing decisions, would use objective demographic data and a quantitative consumer behavior theory to calculate the sales resulting from various marketing plans. He would combine these results with other factors, such as cost and market share, in a systematic way to arrive at a decision.

B. Stage 2: Advanced Beginner

Marginally acceptable performance, perhaps typified by the trainee attempting his first job, comes only after on-the-job coping with real situations in which the performer notes, or a mentor points out, recurrent meaningful *situational* components. The elements, in terms of which the decision-maker who is an advanced beginner understands his environment, include these situational components in addition to the context-free attributes used by the novice. We shall hereafter call these situationally-learned components *aspects*. The student can develop, or an instructor can formulate, principles dictating actions in terms of attributes and these aspects. We call such principles, which presuppose experience-based meaningful elements, *guidelines*. The guidelines treat all attributes and aspects as equally important and are formulated so as to integrate as many as possible.

The beginning driver learns to recognize the (occasionally occuring) aspect that another car is approaching an intersection where it should yield in such a manner as to make it plausible that it will not stop. He combines this aspect, when present, with others concerning visibility, the behavior of the car following him, etc. and with attributes such as the most recent instruction from his teacher, his speed, the gear he is in, etc. and decides on a hopefully appropriate action. To the extent that intuitive, more global, aspect recognition replaces much of his prior, conscious, attribute-monitoring efforts, he can now spare some attention for conversation with an instructor or passenger, although the large number of aspects and attributes being considered (many of which, for the more experienced driver, would be ignored as irrelevant in a particular situation) still makes driving an exhausting experience. Some typical chess aspects are "weakness on the king's side," "over-extended," and "unbalanced pawn structure," and the advanced beginner knows how to bring about and diminish these aspects, and which are to be sought and which avoided. A marketing decision-maker, if an advanced beginner, would consider the introduction of various possible new products as well as the decision to introduce no new product at all. He would evaluate such aspects as the quality of his company's current product positioning as revealed by one or more two-dimensional product-positioning maps [22]. He might also consider the subjectively assessed probability of a recession, as well as his company's level of knowledge of the production processes required by each proposed new product, etc. He would weight these aspects, and also various attributes, in computing an index of merit for each proposed product and for the standpat decision.

The ability to recognize such aspects as a car not about to stop or poor product positioning comes only after experiencing many examples of the aspect in question. Then, and only then, can the performer recognize a component of his current situation as similar to something already experienced and named. There is no consciousness of having acquired rules which allow the identification of aspects on the basis of collections of attributes. This human ability to recognize something on the basis of experienced concrete examples, *without consciously doing so by applying strict rules to objectively identifiable components of the scene*, simultaneously accounts for the improvement of human performance with real-world experience and the impossibility of using introspection concerning attributes and rules of combination as a basis for constructing formal models representing what has been learned.

While there is no in-principle argument proving that the brain's organizing and storing process which produces similarity recognition could not take the form of *unconscious* abstract rules operating over context-free attributes (i.e., information), there is not a shred of experimental evidence supporting this information-processing speculation. It seems more plausible, as we have argued in detail in [23], that what is stored is simply a brain-state record (the chemical and physical state of various neurons, etc.) in no way decomposed into "bits of information" such as feature lists. That recognition without analysis is possible is shown by the fact that character recognition devices using optical holography currently exist that can perform, virtually instantaneously, such tasks as fingerprint recognition. Rather than working with attributes of the object to be recognized (i.e., information), they use optical wave-interference patterns to determine what mathematicians would call the cross-correlation of the complex amplitude transmittances from the scene to be recognized and the reference object [24].

Dr Karl Pribram, a Stanford neurophysiologist who has spent the last decade studying holographic memory, explicitly notes the implication of this sort of process for recognition and decision-making. When asked in an interview whether something like holograms stored in the brain would allow a person to make decisions spontaneously in very complex environments, he replied, "Decisions fall out as the holographic correlations are performed. One doesn't have to think things through ... a step at a time. One takes the whole constellation of a situation, correlates it, and out of that correlation emerges the correct response" [25].

C. Stage 3: Competence

Competence, typified by the relatively inexperienced middle manager, develops when the performer begins to see his actions in terms of long-range goals or plans. The performer is consciously aware of these plans, and the goal or plan dictates to the performer which attributes and aspects of the current and contemplated future situation are to be considered most important *(salient)* and which can be ignored. Hence a plan establishes a perspective, and the competent performer chooses a plan after considerable conscious, abstract, analytic, contemplation of the problem.

A competent driver, aware that his goal is arrival at a certain destination in minimum time, thinks about alternative routes and about prior such trips and their results and calculates what appears to be the best route. The chess player, when competent, assesses the board position, decides upon a goal (such as, attack on the king's side) and calculates his move paying great attention to weakening the opposing king's defense and taking little or no heed of possible weaknesses in his own position that his attack may create. After each opponent's move he recalculates his goal, frequently switching plans when the unforeseen occurs. The competent marketing manager may decide, after examining all elements of a situation, to enter a certain market. Based on this determination, certain attributes and aspects concerning product positioning would be seen as salient while other elements of the situation (those arguing against entering the market at all) would now be ignored. The proper product would be chosen based on evaluation in terms of a criterion involving only the salient elements.

D. Stage 4: Proficiency

Eventually, after a performer has considerable experience in a certain area, various types of situations have been encountered many times, various different plans have been rationally chosen and results observed, and a sense has unconsciously developed for the best plan in such a situation. Furthermore, experience has taught what typical events to expect in a given situation and what modified plans to adopt in response to these events.

Recall that plans dictated salience (the relative importance of various aspects and attributes) so experience has created, in the brain, records of many typical situations, each with its own perspective (i.e., pattern of relative saliences), and also, based on what situations typically were successors of each situation, a web of connections between these records. Except in unusual circumstances, the performer will be experiencing his current situation as similar to some brain-stored, experience-created, typical situation (complete with its saliences) due to recent past history of events which have produced a certain trajectory through his web of recorded typical situations. Further events will cause further movement in this web of perspectives. Hence he will experience his situation at all times through a perspective, but rather than consciously calculating this perspective or plan, it will simply present itself to him. Changing events will cause changing perspectives, not due to any conscious calculation, but due to experiencing the changed situation as typified by a neighboring brain-record in the experience-created web of connected brain-records.

Attributes and aspects are now explicitly identified, if at all, only *after* the situation has been experienced as typified by a certain brain-record, and they appear to be more of less important (salient) depending upon that brain record. If decision is required, elements and their salience *must* be explicitly identified, because the proficient performer uses a learned principle, which we call a *maxim*, to determine the appropriate action given the salient elements. Experience, having taught what to expect in recognizable whole situations, now allows the identification in particular situations of that which is normal, yet absent. Salient elements may therefore now include properties that are significantly *not* present, as well as those present, in a situation. Only those elements which may be identified and consciously abstracted from all the stimulae, conscious and unconscious, named and unnamed, that are impacting the performer can be used for maxim-based proficient decisions. These by no means cover the entire extent of the performer's real understanding that led to his experiencing his current situation through a particular perspective with its attendant pattern of saliences.

Prediction or decision-making not only improves due to holistic understanding, but becomes less labored since experience has taught which of the many attributes and aspects present are the important ones.

A proficient driver, approaching a curve on a rainy day, may sense, based on prior experience, that he is going too fast. He then consciously estimates the appropriate speed, based on such salient elements as angle of bank, wind velocity and direction, criticality of time, etc. Driving is no longer exhausting. The chess player involved in his game now sees aspects such as "unbalanced pawn structure" as either crucial or irrelevant due to the brain-record currently typifying the chess position. What particular brain record this is depends not only on the actual current board position but the particular path through his chess-experience-created web of typifying positions that led him to the perspective that now determines his saliences. If asked, he might articulate his plan, such as "attack" or "play for a positional end-game advantage," but this represents only a groping attempt at consciously naming what is really only a pattern of saliences in a reference brain-record. He uses maxims to decide on moves which change the crucial elements of the position to his advantage. The proficient marketing decision-maker, after sufficient unsolicited evidence has accumulated, might intuitively, based on experience, perceive a need for considering product repositioning. Further solicited evidence might convince him, without conscious computation, that a need indeed exists. Given this need, certain attributes and aspects would be perceived as salient in making a decision about how to address this need. Typical salient aspects, unique to this particular issue, might be: the risk of anti-trust action, the level of company knowledge with respect to a certain contemplated new product, etc. The particular repositioning decision chosen would be selected systematically from among several alternatives through evaluation by means of a criterion composed of such considerations.

Proficiency is perhaps typical of most experienced *middle* managers. These managers allow themselves the prerogative of intuitively sizing up whole situations, but their schooling, habits acquired while inexperienced, and need for justification to higher authority, motivate them toward decision by explicit evaluation of alternatives on the basis of comparison of salient elements.

E. Stage 5: Expertise

The expert performer in a particular task environment has reached the final stage in the step-wise improvement of mental processing which we have been following. Up to this stage, the performer needed some sort of analytical principle (rule, guideline, maxim) to connect his grasp of the general situation to a specific action. Now his repertoire of experienced situations is so vast that normally each specific unresolved situation seen with particular saliences due to prior experience and recent history immediately dictates an *intuitively* appropriate response. This intuition is possible because each typical whole salienced situation, unconsciously synthesized from several experienced concrete situations (see D above), now has associated with it a specific response or type of response which experience has shown to be appropriate.

Nothing less than vast experience with concrete, real-world, situations can produce expertise. Strangely, Howard, in arguing for the inadequacy of human decision-making by citing laboratory evidence involving poor performance of tasks *unlike* those required in the real world, dismisses the need for observation of business performance in its naturalistic setting because "if the natural decision-making of executives is to be excellent, then some magical change must come over them when they put on a three-piece suit and sit behind a desk" [26]. What Howard seems to have missed is that the magical change occurs very gradually, after several dozen three-piece suits have been put on and worn out, and is the result of the acquisition of vast concrete experience.

The expert driver, perhaps engrossed in conversation, may sense that he is approaching a curve on a rainy day at too high a speed. He will automatically slow the car until his speed feels right, without ever being consciously aware of what he has done. The magnitude and importance of this change from analytic thought to intuitive response is evident to any expert driver who has had the experience of suddenly reflecting upon what he is doing, with an accompanying degradation of performance and the disconcerting realization that rather than simply driving, he is controlling a complicated mechanism. By virtue of previous chess experience with actual meaningful board positions which have occurred in ongoing games or the involved study of such positions, an appropriate move generally presents itself immediately to the chess expert as he views a current chess position (or a foreseen one) complete with saliences which present themselves to him based on both prior experience and recent moves. Of course, calculations then follow. Their role is discussed in Section III. Occasionally, the intuitively correct move may be accompanied by (or replaced by) an intuitively correct new type of strategy or an intuitive suggestion of new strategies worth investigating. The expert marketing decision-maker would, after accumulating sufficient solicited and unsolicited evidence, intuitively decide that a certain new product should be introduced. The situation would be seen as essentially like certain of those that he had experienced or observed his competitors experience where such a strategy had proven profitable. After the need had been perceived and the resolution occurred to him, he might check his decision by conscious examination of certain attributes and aspects. He would not normally evaluate other possible repositioning decisions by some explicit index of merit to arrive at his decision or to confirm it. Only if he needed to justify his decision to some possibly recalcitrant higher authority, might he do this sort of comparative analysis, after the fact.

F. Summary

The skill-acquisition process described above results from the successive transformation of four mental capacities. Each of the four mental capacities has a primitive and a sophisticated form. Each row in Table 1 represents a mental capacity. In column 1 all four capacities are in their primitive state, and in each subsequent column, one additional capacity has been transformed into its sophisticated form. As a result, there are five columns, and each corresponds to one of our five levels of skill.

TABLE 1

Skill Level / Mental Capacity	NOVICE	ADVANCED BEGINNER	COMPETENT	PROFICIENT	EXPERT
Component Recognition	Nonsitua-tional	Situational	Situational	Situational	Situational
Salience recognition	None	None	Present	Present	Present
Whole Situation Recognition	Analytical	Analytical	Analytical	Holistic	Holistic
Decision	Rational	Rational	Rational	Rational	Intuitive

In reading the table, one should recall the following. The component recognition capacity shown in row 1 first becomes *situational* when the performer confronting a current situation is able to identify certain of its components because they are similar to previously experienced examples of these components. Salience recognition, row 2, is not present at first, and when it develops it first is determined by the conscious choice of a goal or plan (competent) and later what stands out as salient in a situation is the result of concrete experience combined with the recent past history and is *experienced* rather than consciously chosen (proficient and expert). The whole situation recognition capacity shown in row 3 is, at first, analytically deduced by combining component elements. It first becomes [illegible]*istic* when the performer recognizes his current whole situation because it is perceived as similar to a typical, already salienced, whole situation synthesized from his prior concrete experiences. In row 4, the performer refines his repertoire of typical whole situations to the point that predictions or decisions, learned through experience, *intuitively* accompany situation recognition without need for conscious calculation.

III. ANALYTICAL VS. SITUATIONAL UNDERSTANDING

The significant pattern pervading the skill-acquisition process, as we have described it, is the progression from abstract, rational understanding and decision-making in terms of isolated elements and rules relating them, to immediate situation recognition and response based on holistic similarity to prior concrete experiences. At the most elementary level, everyone takes for granted that recognition and decision can take place without conscious analysis in terms of component parts. After seeing a sufficient number of examples of colored objects, with an accompanying naming of the color, a small child can easily classify by name a typical green color patch, without any conscious decomposition into parts and recombination by rule. Almost certainly we have here a situation where the physical stimulae produce in the brain, already conditioned by experience, a neurophysiological state which directly evokes the word "green" without any intermediate processing of distinguishable facts (i.e., information). Similarly, no one seriously argues that the smell of coffee is recognized through conscious decomposition into component smells, or that a small baby, before learning about facial features such as nose, mouth, etc., recognizes his Mother's face by means of conscious identification and combination of elements. Although, at this elementary level of perception, when we cannot conceive of a conscious information-processing explanation for behavior we are quite willing to do without it, a common post-seventeenth century Western prejudice is to conjecture that behavior was produced by conscious processing of component elements whenever such as explanation is conceivable.

A recent psychological discovery, however, seems to indicate that concrete experience can immediately and by itself, directly dictate decisions in complex situations which are susceptible also to conscious logical treatment. An abstract logical task involving a conditional rule was studied extensively by Wason in 1966. Here is one example of the problem Wason studied and his results:

> "You are presented with four cards showing, respectively, 'A', 'D', '4', '7', and you know from previous experience that every card, of which these are a subset, has a letter on one side and a number on the other side. You are then given this rule about the four cards in front of you: 'If a card has a vowel on one side, then it has an even number on the other side.'
>
> Next you are told: 'Your task is to say which of the cards you need to turn over in order to find out whether the rule is true or false.'
>
> The most frequent answers are 'A and 4' and 'only A'. They are both wrong. The right answer is 'A and 7' because if these two stimuli were to occur on the same card, then the rule would be false but otherwise it would be true. Very few highly intelligent S's get the answer right spontaneously; some take a considerable time to grasp it; a small minority even dispute its correctness, or at least remain puzzled by it ..." [27].

In 1972, it was demonstrated that the subject's performance dramatically improves if the selection task relates more closely to his experience.

> "The subjects were instructed to imagine that they were postal workers engaged in sorting letters on a conveying belt; their task was to determine whether the following rule had been violated: 'If a letter is sealed, then it has a 5d stamp on it.' The material consisted of four envelopes arranged as follows: the back of a sealed envelope (p); the back of an unsealed envelope ($\bar{p}$); the front of an envelope with a 5d stamp on it (q); the front of an envelope with a 4d stamp on it ($\bar{q}$). The instructions were to select only those envelopes which definitely

> needed to be turned over to find out whether, or not, they violated the rule. There were twenty-four subjects and they performed the task under both this 'concrete' condition, and under an 'abstract' control condition in which arbitrary symbols were associated in the usual way. Under the 'concrete' condition twenty-two subjects were correct, and under the control, 'abstract' condition seven were correct" [28].

Either we have here an example of a situation in which concrete experience has taught the appropriate response without any intervening stage of abstract, logical understanding, or else concrete experience has created a nonconscious logical understanding so inaccessible to the conscious mind that, not only can it not be verbalized, but it can barely be comprehended when explained by others. While we accept the former interpretation, adherents of the information-processing position would presumably prefer the latter. Whichever explanation one accepts, we certainly have here an example of experience-based situational understanding well beyond what can be articulated.

The eminent Dutch psychologist and chess master Adriaan deGroot, after more than thirty years of careful study of chess ability, argues persuasively for the existence of a nonverbalizable mental capacity (distinct from factual knowledge) which he calls "intuitive experience." We quote his conclusions:

> "Knowledge (knowing that ...) can be verbalized while intuitive experience cannot. Knowledge can be explicitly formulated by the subject and thus communicated, in words, to others; it is retrievable from memory by verbal cues. Intuitive experience, on the other hand, is intuitive know-how--as distinct from knowing that ... --that is only actualized by situations (on the chess board or in the thought process) where it can actually be used" [29].

> "The differentiated system of thought habits (routines) which forms the essence of chess mastership, consists partly of knowledge but largely of intuitive experience" [30].

> "In fact, most *skills* depend largely on 'intuitive experience', i.e., on a system of methods that one cannot describe" [31].

DeGroot undertook his research in the belief that superior logical ability and creativity would turn out to account for masterful chess performance, but his studies led him to conclude instead that it is a nonverbalizable perceptual ability that distinguishes masters from lesser players [32]. These studies showed that, when presented with unfamiliar positions that had actually occurred during master play, masters almost immediately (usually in less than 10 seconds) perceived them as possessing certain salient problems and opportunities, and frequently the appropriate move simultaneously came to mind, prior to any conscious analysis. Lower class players spent considerable time performing conscious analysis, yet rarely, even then, selected the appropriate move. After concluding experimentally that no identifiable analytic ability separates the master from lower class players, which in chess includes "experts" (a technical chess classification), he writes:

> "If this striking difference is not rooted in tangible, quantitatively computable properties of the actual thought process, on what is it based? We have already answered this question: on the fast and efficient problem formation and specialization which derives from the (grand)masters' 'experience'. He immediately knows what it is all about, in which direction he must search; he immediately 'sees' the core of the problem in the position, whereas the expert player finds it with difficulty--or misses it completely ... . The master does not necessarily calculate deeper, but the variations that he does calculate are much more to the point; he sizes up positions more easily and, especially, more accurately" [33].

> "The gist of the argument is that a chess position, and a fortiori an entire game are *typical* to the master. A chess position is easily recognized as one belonging to a certain class, that can be handled in a certain specific way" [34].

The deGroot reference to the well-known practice of the chess player of calculating out into the future should not be interpreted as evidence that skilled decision-makers in other domains do likewise. This examination of possible futures becomes feasible in chess because the objective and complete nature of a chess position makes a future position as intuitively meaningful as a present one. Furthermore, the fact that masters perform almost as well when restricted to 10 seconds per move indicates that these calculations are not crucial to performance.

DeGroot refrains from explicitly speculating about the mental procedures underlying "intuitive experience," but at times he seems to implicitly credit an unconscious, nonverbalizable, *yet analytical*, process. Another respected researcher, historian of science Thomas Kuhn, shares deGroot's view that superior skill derives from unconscious recognition, based on experience, of the typical, but he explicitly denies that unconscious analysis is involved. In his seminal work on the conduct of science, *The Structure of Scientific Revolutions*, Kuhn argues that scientists working in any particular branch of science at any particular time understand what constitutes acceptable scientific practice, not by applying some criterion or set of rules, but by seeing similarity to paradigms, the *specific examples* of good scientific work they have found in their textbooks.

> "Scientists can agree that a Newton, Lavoisier, Maxwell, or Einstein has produced an apparently permanent solution to a group of outstanding problems and still disagree, sometimes without being aware of it, about the particular abstract characteristics that make those solutions permanent. They can, that is, agree in their *identification* of a paradigm without agreeing on, or even attempting to produce, a full *interpretation* or *rationalization* of it ... . Indeed, the existence of a paradigm need not even imply that any full set of rules exists" [35].

Later Kuhn asserts, more strongly:

> "I have in mind a manner of knowing which is misconstrued if reconstructed in terms of rules that are first abstracted from exemplars and thereafter function in their stead" [36].

Kuhn is aware that unless historians of science can "discover what isolable elements, explicit or implicit, the members of [the scientific] community may have *abstracted* from their more global paradigms and deployed as rules in their research" [37] the way in which a piece of scientific research is seen to be similar to the paradigm will seem to be incomprehensible, and the judgment of similarity, in the absence of a rule-like criterion, will seem to be subjective, and arbitrary. Kuhn, however, insists that neither he nor anyone else has ever found such rules or criteria, and thus historians must face the possibility that:

> "The practice of normal science depends on the ability, acquired from exemplars, to group objects and situations into similarity sets which are primitive in the sense that the grouping is done without an answer to the question, 'Similar with respect to what?'" [38].

To summarize, the highest level of skilled performance depends on an ability to rapidly and accurately perceive a current situation as similar to a certain typical one which past experience has caused to be stored in the brain. We conjecture that what is stored is merely a brain-state, in no way decomposed into separate components that can be identified with facts. Believers in information-processing, on the other hand, must hypothesize an unconscious decomposition into facts and recomposition by means of rules. Be that as it may (and neurophysiology will not resolve this disagreement in our lifetimes, if ever), research shows that these experience-created typical instances, and the facts and rules, if any, that produce them are unavailable to the *conscious* mind of the expert. Consequently, they are nontransferable to the mind of the modeler of expertise.

IV. THE EXPERT EXECUTIVE DECISION-MAKER

In the previous two sections we laid out, in quite general terms, our notion of the progressive changes which experience produces in a performer's way of perceiving and coping with his task environment. We sketched out some examples in only sufficient detail to clarify our terms. We now examine in more detail what we claim, based on skill-acquisition experiences in related areas, are the typical acts and mental activities of an experienced and expert business executive when he is fulfilling his decisional role. We consider, not the exceptional, totally novel situation that may occasionally arise, but rather the normal--unique yet not unfamiliar--setting.

The background, or context, in which an executive operates includes his sense of normal situations, learned through experiencing throughout most of his career concrete examples of untroubled, stable, business environments. Also included in his background understanding, and learned through concrete experience, is his sense of proper executive prerogatives. This contextual background constitutes a part of his situational understanding, and is a much richer source of personal guidance than any articulated principles that he might attempt to abstract in order to educate others. Heidegger and several other influential contemporary European thinkers have made the pervasive, yet tacit, nature of trained-in contextual human background central themes in their philosophies [39], [40], [41].

Much of an executive's daily time, according to Mintzberg's careful observations of managerial behavior [20], is spent in communication, and Mintzberg observes that the executive prefers concrete, current, information, even gossip, speculation, and hearsay, to the abstracted summary information contained in routine reports flooding his office [42]. This bias of excellent managers toward live action and constant customer contact and against abstracted reports is confirmed in [1]. We speculate that this current, concrete, information, after interpretation based upon the manager's current perspective, forms a pattern in his brain (or unconscious mind, if you prefer the information-processing interpretation) which is constantly compared to the many stored brain-state patterns (or unconsciously remembered information patterns) recorded as typical untroubled business environments. If no match is found, to a suitable level of tolerance, the executive begins to see the current situation as one in need of resolution. As both solicited and unsolicited information flows to him, his brain-state (or unconscious information state) begins to match, within some tolerance level, that of some recorded, experience-based, typical unresolved situation and his sense that action is appropriate heightens. Quite wisely, few, if any, management scientists propose modeling this crucial recognitional phase of good management practice. Unmodelable, intuitive, situational recognition ability is currently a culturally acceptable concept, whereas, inexplicably, intuitive decisional wisdom is unacceptable unless rationalized.

The brain-state (or unconscious memory) that triggered the awareness of a need for resolution was created in the course of experiencing certain previous unresolved situations, and in these earlier situations decisions were made and results observed. Hence, based on how things turned out the previous times, a learned successful response or type of response is associated with the brain-state (or memory). This response, or strategy, is the one that now springs to the manager's mind. Experience has not taught the manager why this intuitive resolution is appropriate, only that in the past it has worked.

What is meant above by "response, or strategy" depends heavily upon the nature of the problem at hand, upon the manager's experience with that type of problem, and upon his perspective as determined by recent events. The response may be a definitive action, a preferred type of action with details left to subordinates, a request for further information of a certain type which the manager's perspective indicates is salient, but lacking, or the response may even be the conscious application of learned heuristic principles. The latter response would be appropriate if the manager has learned from past experience what are useful and what are inappropriate principles, but lacks the experience with a sufficient number of concrete cases to directly know what to do. In this case we would not characterize the manager as expert in this particular area, but rather as proficient. Perhaps some problems are so complex (involve, as seen from a particular perspective, so many salient factors) that no manager ever progresses, with respect to these problems, beyond proficiency.

Recall that, for the experienced expert, situational understanding is revealed through a perspective. This point of view is not something consciously chosen by the executive, but results from his recent business expectations and experiences. A good executive, faced with an important decision, will challenge his current perspective. He will do this by consciously focusing his attention on issues that he finds himself dismissing as nonsalient. He will also ask trusted experts what they would do, and what they see as salient. When he does this, either a different appraisal of the situation will spring to his mind, with new aspects seen as salient, or else the issues originally seen as unimportant will continue to appear to him as such. If he finds he can, by such attempted refocusing, radically alter his situational understanding and probably also his prediction or decision, his confidence in his original perspective will be shaken. He will then solicit additional information, in the hope that all but one of the competing two or more perspectives will fade from mind. If time permits, he will act only after this has happened. If not, he will decide on the basis of that perspective which seems slightly more compelling, or choose defensively so as to protect against all possibilities if he can discern no preference.

According to Mintzberg, "The pressure of the managerial environment does not encourage the development of reflective planners, the classical literature notwithstanding. The job breeds adaptive information-manipulators who prefer the live, concrete situation. The manager works in an environment of stimulus-response, and he develops in his work a clear preference for live action" [43]. Mintzberg's *observation* that "If the manager does plan, it is not by locking his door, puffing his pipe, and thinking great thoughts" [44] accords with our description. His *theoretical speculation* is that managers are information manipulators who do not think analytically due to pressures of the managerial environment. Our theory, on the contrary, is that they seek and use information mainly to facilitate a nonanalytic situation-recognition ability. Mintzberg's information-processing speculation which pervades an otherwise excellent book reporting careful observation, leads to recommendations that seem inconsistent with his own evidence. For example, he observes that a skill must be learned on-the-job, not through abstract cognitive learning about the skill or even learning through simulation (case studies) [45]. Yet he writes elsewhere, "In Chapter 4 it was suggested that managers build implicit models for themselves to help them in making choices. Analysts can formalize this process, with the aim of developing better models for the managers" [46]. If it were true that these implicit models could be articulated, or successfully formalized by any method, then contrary to Mintzberg's own observation that skill must be learned on-the-job, a skill could be taught by abstract cognitive learning.

What is significant here, however, is what *is* in agreement between our theory and Mintzberg's observations. In a real-world business environment, as in chess and in elementary color perception, alternative decisions need not be, and generally are not, enumerated and evaluated prior to decision. Situational understanding not only facilitates recognition, but, at the same time, resolution.

Let us now examine, in some detail, the prospects for formal modeling of expertise of the type practiced in management science in the light of our notion that the highest level of skill is the result of situational understanding and that this understanding is created, unconsciously, from concrete experience, and cannot be verbalized.

V. IMPLICATIONS OF SITUATIONAL UNDERSTANDING FOR FORMAL MODELING

The essence of formal modeling is the decomposition of a situation into its isolable elements, and its recomposition by means of rules relating those elements. With the exception of decision analysis, which we shall consistently treat separately in what follows, the elements are of two types. Some, called *data and state variables*, are facts describing the current situation. It is assumed that these facts cannot be changed instantaneously. Generally they are context-free attributes such as physical facts (e.g., the available amount of a resource, current demand rate), economic indices (e.g., the rate of inflation as computed by a specified formula, interest rates), and social indicators (voting patterns, results of attitudinal surveys). In more sophisticated models they can also be quantified subjective aspects assessed on the basis of situational experience (e.g., the probability of a major earthquake in San Francisco this decade, the minimal strike-averting wage package). The second type of element, present in optimization but not predictive models, is called a *decision variable*. These are properties of the current situation which, it is somewhat arbitrarily assumed, can be instantaneously changed. Examples include production rates, tax structures, quantity and kind of information to be purchased, etc. Rules relating elements are of three types, not all of which are present in all models. *Constraints* stipulate admissible combinations of state and decision variables. *Dynamic rules* predict, perhaps stochastically, future elements, given current elements and, in optimization models, decisions. *Criteria* assign indices of merit to combinations of elements and decisions.

Since, as we indicated in Section I, most real-world situations do not come predigested into elements and rules, the decomposition and recomposition required by formal modeling must be artificially supplied. The dogma of operations research asserts that the decision-maker or his appointed expert surrogates, not the modeler, should provide this structuring. We shall investigate this structuring process with respect to the two types of elements and the three types of rules, in each case treating decision analysis as a special case.

A. Data and State Variables. The experienced decision-maker has been observed to have a voracious appetite for concrete, current, information, even gossip, speculation, and hearsay, but not for routine reports or abstract discussion. Yet it is the abstracted, summary, statistics typical of operating reports that constitute the data and state variables of models. This element of a model is, fortunately, generally available from reports. But the determination of salience (i.e., what to include), which the modeler must elicit from the expert, is an abstract judgment for which experience has ill-prepared the action-oriented decision-maker. The expert must regress to what we characterized in Section II as proficient thinking to satisfy the modeler's demands. If the model is dynamic and stochastic, future chance events may change the decision-maker's perspective (i.e., sense of what variables are salient). If the decision-maker attempts to reason-out what his perspectives would be, a further regression of the model to the point where it represents merely competent understanding will result. If the model includes as many attributes and aspects as possible, it will simulate the advanced beginner, and if, in an attempt to be objective, only attributes are included, only novice-level results should be anticipated.

A notable exception is decision analysis. Since the future is described in decision analysis as "the present, followed by decision A, then chance event B, then decision C, etc." the decision-maker need furnish to the modeler no abstract characterization of the present, so the above discussion does not apply. To facilitate Bayesian probability computations, however, the present is sometimes conceptualized as described by a subjective probability distribution defined over a set of abstracted "states of nature." Then the prior probabilities play the role of state variables, and the expert decision-maker is asked to furnish an assessment of quantities that he need never think about when choosing action on the basis of situational understanding. For example, experience can tell me to avoid Central Park at night without teaching me much about the probabilities of various states of nature, the configurations of criminals and police.

B. Decision Variables. We have argued that many decisions are made intuitively without consciously considering alternatives. If pressed, however, there is little doubt that an expert decision-maker could furnish a fairly comprehensive set of plausible choices (presumably including the intuitively correct one) in his *current* situation. Choice of decision variables at *future* times as required in dynamic optimization models, however, presents special problems.

What these are will become clear below.

In decision analysis, the decision-maker is asked to suggest plausible future alternative decisions based upon an imagined future described either as the present followed by a specified sequence of alternating chance events and decisions or by the probability distribution of the uncertain state of nature. While in a real-world current situation decisions intuitively present themselves to the involved expert decision-maker based on prior experience, the abstracted and grossly simplified nature of the constructed future as it is described in a decision analysis forces the decision-maker to reason out analytically plausible future decisions rather than invoke experience. An experienced driver is capable of almost automatic reaction to a wide range of situations, yet he is unable to accurately reason-out how he would respond in a hypothetical situation that is skeletally described by information about velocity, visibility, road condition, etc. The *knowing how* to respond derived from intuitive experience, gets replaced by conscious, analytical, *knowing that*, a distinctly inferior mode of understanding. Rex Brown, a consulting decision analyst with extensive experience and the author of a 1970 Harvard Business Review article assessing the technique, perceives this as a major problem with the technology of decision analysis. He writes:

> "A critical technical bottleneck now appears to be in the *structuring* of the model, especially in the handling of choices to be made at times subsequent to the initial act. Such 'subsequent acts' are particularly critical in decisions where learning is involved. Severe, but often undetected, problems can arise in attempts to model subsequent acts using conventional paradigms of statistical decision theory" [47].

> "In such analyses, it is assumed that as the process under analysis unfolds in time, the decision-maker when faced with a subsequent act will *surely* make the choice from the options available to him which was judged to have maximum expected value *at the time of analysis*. No allowance is made for the perceived analysis of the problem to change as time goes by" [48].

This suggests regression to stage 2 of skill acquisition, advanced beginner. Plausible future decisions and, as we shall see later, also both the appropriate future dynamics and the desirability of future situations must be reasoned out in the present from a decomposed description, without even the benefit of a meaningful perspective other than that of the present. The richness of real-world detail (even though the decision-maker has no conscious awareness of much of it) and the sense of human involvement that are needed to evoke situational understanding are absent.

C. Constraints. Some constraints separate the objectively possible from the impossible. For the expert, experience also separates the acceptable from the unacceptable. Certainly there is some loss of expertise when the expert attempts to rationalize this knowledge in terms of ad hoc elements combined into constraints. But no new difficulties occur beyond those already discussed.

D. Dynamical rules. While the expert may have a strong intuitive sense that if action A is chosen, result B will occur, a model requires an explicit rule, operating upon its elements, that replicates this prediction. No such rule exists in the expert's consciousness. If the prediction involves implications of actions taken in the present, an ad hoc rule must be constructed that fits various of the expert's explicitly stated intuitive predictions. Since the usual intention of a model is to extrapolate knowledge beyond those cases that a decision-maker can explicitly handle, however, it must remain an act of faith that these rules reflect the decision-maker's intuitions in all cases. If the decision-maker's predictions are experience-based, but not rule-based, there is no reason to anticipate the universality of any rule. Worse yet, if the dynamical rule involves outcomes of actions taken in the future with the future described only by the values of state variables, intuition based on concrete experience is impossible.

In decision analysis, the dynamic rules are subjective probabilities of outcomes. These subjective probabilities are not elements that generally enter a decision-maker's mind, even in a present, real situation, since experience directly and unconsciously teaches only the desirability of actions. Probabilities of outcomes can, at best, be tentatively and unreliably reconstructed from conscious memories of specific cases. For example, I have learned from experience not to trust BART, the local rapid transit system, but I do not remember what fraction of my trips encountered bad experiences of various particular types.

This difficulty with providing subjective probabilities in the present is compounded when the future is modeled. When probabilities are assessed for the outcomes of future decisions, taken in skeletally described future situations, the expert decision-maker loses all intuitive sense, for reasons discussed above, and his answers certainly are no longer of expert quality.

There is one further thing that experience teaches concerning the future which seems to defy any formal modeling. The occasional inaccuracy of even the most expert prediction teaches us to expect, or at least not to ignore, the unexpected. This produces wise delaying behavior in some decision situations which cannot be justified on rational, event enumerating, grounds. In this regard, Rex Brown points out [49] that information-buying decisions may be undervalued in formal analyses, because the delay involved in acquiring information may itself have value. While "the unexpected" can be assigned a subjective probability at any chance-event fork in a decision analysis, probably with as much accuracy as any other chance event, it is virtually impossible to enumerate decisions which might be taken in the future in response to "the unexpected," nor can one sensibly be expected to assign a value, even probabilistically, to a future situation described only as "unexpected."

E. Criterion. Conventional optimization modeling frequently uses weights, or trade-offs, to combine its isolated elements into a scalar criterion. Yet the studies cited earlier, and the well-known one by economist Charles Lindblom [50], generally agree that experienced decision-makers do not think in these terms, at least not until after they have chosen their decision and are rationalizing it (in both senses of the term) to themselves or for others [51]. During this rationalization process one cannot help but see as salient, and therefore worthy of inclusion in a formal justification of a decision, mainly those elements that argue for the desired conclusion. Furthermore, subjective weights, which really don't exist, are arbitrarily attached to the elements comprising the index of merit in such a way as to produce the desired result. This rationalization is seldom intentionally dishonest, serving rather to relieve the anxiety that accompanies involved, intuitive choices in a culture that publicly deifies "detached, objective analysis."

In decision analysis, no trade-off assessment is explicitly required, although multi-attribute utility theory uses such questionable data. All that is needed, in principle, is an assessment of a "whole" situation, which is described as the present followed by a particular sequence of alternating decisions and chance events. Here, however, we encounter the same difficulty as was described under B above. Such an abstracted future is, of necessity, skeletally described compared to a real present that is concretely experienced, no matter how many events and actions are explicitly included. The decision-maker, consequently, cannot draw upon the intuitive experience that only a real-world situation can evoke. (Recall that in chess the case was different. The future was completely, not skeletally, described due to the objective properties of a board position. In this case, thinking ahead can terminate with an appeal to intuitive experience.) To attempt to *reason out* how one would feel in a hypothetical future is to abandon the wisdom of experience.

V. CONCLUSIONS

We have seen that formal models, by their very decomposition into analytically recombined elements and by requiring the *reasoning-out* of changes in perspective that evolving events would produce, mimic, as best, competent behavior. Worse yet, unless experience-based, subjective aspects are included as model elements, the model will have tapped only the even more inferior understanding of the novice.

A formal model using, like the novice, only objective attributes has the attractive feature, desired by advocates of "scientific decision-making," that it lays bare and arguable the complete explanation of a decision. Hammond and Adelman clearly articulate this goal when they reject the "use of scientists as policy advisers who have somehow gained a reputation for wisdom in the exercise of their judgment" as "ascientific: they leave the body politic at the mercy of a cognitive activity which remains as much a mystery as ever" [52]. We do not disagree with Hammond and Adelman's assertion that "A scientific approach would emphasize that judgment is a human cognitive activity and is therefore subject to scientific analysis, as are all natural phenomena" [53], but, unfortunately, a scientific analysis of cognition beyond the level of the novice is not currently possible. If the information-processing speculation is correct, we must await the discovery of techniques for extracting all of the unconscious knowledge somehow created in the mind by means of concrete experience; and, if brain-state similarity alone explains situational understanding, we must await the even more distant discovery of techniques for recording the physical-chemical state of the entire human brain while it is in the act of cognition.

Meanwhile, the choice remains: transparent and novice or mysterious and expert. Since, in all areas where skill can be objectively assessed (e.g. chess playing, automobile driving, card playing, foreign language speaking and understanding, face recognition), the similarity-based, situational understanding that is actually used by the experienced human being ultimately leads to better performance than does the formal approach often practiced by beginners, decision-making and prediction based on proven expertise should neither be replaced by formal models nor should proven experts feel any obligation to explain their decisions or predictions in formal terms. Of course, during the period when a relatively inexperienced decision-maker *begins* to adopt the intuitive, experience-based, approach, it is unclear whether carefully constructed formal models could improve on his intuitions. At what point a business decision-maker has integrated sufficient experience in the area of a particular problem to outperform any formal model is never clear. That particular decision must be made by the business expert, based on his intuitive sense of self-assurance.

What should the experienced decision-maker do if he finds himself torn between two or more intuitively equally attractive resolutions of a situation? Such a decision-maker should seek further information and the advice of trusted aids. Modeling can be used to clarify any objectively factual attributes of the problem. But a model cannot profitably be used to aid the choice between decisions that seem equally attractive given the executive's perspective, or between equally attractive perspectives, each suggesting its own decision. The reason, of course, is that decisions and perspectives intuitively spring to mind on the basis of prior concrete experiences through a process that is unconscious and hence totally inaccessible to models. Once a decision-maker, torn between two or more equally attractive decisions, foresakes his *wisdom* in search of *rationality*, flipping a coin is more rational than formal modeling, because it is as reliable, and cheaper.

Can an executive, seeing his situation and its resolution through one perspective, use modeling to open his mind to other perspectives? While, as we noted in Section IV, focusing upon aspects of a situation that appear nonsalient can sometimes bring to mind a differing perspective worthy of consideration, models do not seem very helpful in this respect. The executive can ask an adviser who is advocating a different perspective to create a model representing that perspective, although he himself does not find it at all intuitively compelling, but there seems little reason for doing this since the model will represent considerably less than expert understanding, even if its source is an expert. Despite this, some managers may distrust a disagreeing expert but find a contrary model jolting to their perspective. For them the model may usefully serve to dislodge a current perspective. No expert, however, should accept a models's conclusions if they contradict his own intuitions.

And what of the decision-maker who himself is not an expert in a problem area, who finds his consulting experts in disagreement? Since life makes us all more-or-less experts in deciding whom to trust, he should use that expert knowledge to identify the most reliable source of expertise. And above all, he should staunchly resist all offers by modelers to provide a formal model for making that decision.

What if the decision-maker feels non-expert in his problem area, and his advisers are experts in various aspects of the area, but none are expert in its totality? Here we find a proper function for the formal model. And even in this case, the decision-maker should feel comfortable with accepting as elements of the analysis the subjective, nonrationalized, aspect assessments of his expert advisers. Should modeling be commissioned by an executive facing a novel situation, in the totality of which no one is expert, an interesting choice must be made. By including in a large and comprehensive model as many attributes and aspects as seem likely to be relevant and then by excluding those that sensitivity analysis shows to have little impact on the output of the model, a decision or prediction at the skill level that we have called advanced beginner can be anticipated. On the other hand, recognizing that a higher level of skill, which we have called proficient, results when the situation is seen from a perspective reflecting a sense of issues and goals, but also recognizing that the novelty of the problem prevents intuitive experience from causing an appropriate perspective to spring to mind, a decision-maker can seek a variety of small models, each representing a different perspective on the situation. Since each of the various perspectives adopted must be chosen on the basis of conjecture due to the lack of experience-based intuition, no model will necessarily represent proficient understanding, but the totality of the output of these models, each representing a hypothetical competent decision-maker, may be as useful to the decision-maker as the one large model of at best advanced beginner understanding. Of course, the predictions or decisions of the various models representing differing perspectives may disagree, while the one big model including "everything" yields only one recommendation, a comforting situation if the low quality of the understanding represented by the model is ignored.

Management scientists must learn to live, humbly, within the constraints imposed by their inability to model situational understanding. They should model objectively structured situations, and entirely novel unstructured ones. They should construct models of repetitive low-level unstructured operational situations, thereby providing routinization which frees management personnel for more important duties. They can safely offer aid, and comfort, to the relatively inexperienced. They might even offer the experienced expert facing an unstructured situation the opportunity of discovering what sheer computational power can deduce from distinctly inferior understanding. But, if the field is to maintain (or is it regain?) its legitimacy, claims of the decisional and predictive superiority of models must, in this latter case, be assiduously avoided. The expert must be made aware of his own uniquely human capacities and of the inadequacies in these respects of any formal model. In short, practitioners of our discipline must acknowledge its inherent limitations, and provide this information to its clients. The expert can then use this knowledge, and that provided by any models that he still chooses to commission, as he intuitively sees fit.

REFERENCES

[1] Peters, Thomas J., "Putting Excellence into Management," Business Week, p. 196 (July 21, 1980).

[2] Peters, Thomas J., "Manager's Journal. The Planning Fetish," The Wall Street Journal, p. 10 (July 7, 1980).

[3] Lohr, Steve, "Overhauling America's Business Management," The New York Times Magazine, p. 15 (January 4, 1981).

[4] Mintzberg, Henry, "Planning on the Left Side and Managing on the Right," Harvard Business Review, p. 53 (July-August 1976).

[5] Leavitt, Harold J., "Beyond the Analytic Manager, Parts I and II," California Management Review, Vol. 17, Nos. 3 and 4, pp. 5-12 and pp. 11-21 (Spring and Summer 1975).

[6] Kepner, C. H. and B. B. Tregoe, THE RATIONAL MANAGER, Kepner-Tregoe, Inc., Princeton, N. J., 1965.

[7] Howard, R. A., "An Assessment of Decision Analysis," Operations Research, Vol. 28, No. 1 (January-February 1980).

[8] Nisbett, R. and T. Wilson, "Telling More Than We Can Know: Verbal Reports on Mental Processes," Psychological Reviews, Vol. 84, No. 3, pp. 231-259 (1977).

[9] Steiner, George, FIELDS OF FORCE, FISCHER AND SPASSKY AT REYKJAVIK, The Viking Press, New York, pp. 66-67, 1974.

[10] Winkler, R. L. and A. H. Murphy, "Experiments in the Laboratory and the Real World," Organizational Behavior and Human Performance, Vol. 10, pp. 252-270 (1973).

[11] Howard, R. A., "An Assessment of Decision Analysis," Operations Research, Vol. 28, No. 1, p. 12, (January-February 1980).

[12] Howard, R. A., "An Assessment of Decision Analysis," Operations Research, Vol. 28, No. 1, p. 9 (January-February 1980).

[13] Slovic, P., B. Fischhoff and S. Lichtenstein, "Behavioral Decision Theory," Annual Review of Psychology, Vol. 28, pp. 15-17 (1977).

[14] Stael von Holstein, C.-A. S., "Probabilistic Forecasting: An Experiment Related to the Stock Market," Organizational Behavior and Human Performance, Vol. 8, pp. 139-158 (1972).

[15] Slovic, P., B. Fischhoff and S. Lichtenstein, "Behavioral Decision Theory," Annual Review of Psychology, Vol. 28, p. 19 (1977).

[16] Fischhoff, B., "Diagnosing Clinical Diagnosis," Contemporary Psychology, Vol. 24, No. 1, p. 48 (1979).

[17] deGroot, A., THOUGHT AND CHOICE IN CHESS, Mouton, The Hague, The Netherlands, 1965.

[18] Kuhn, T., THE STRUCTURE OF SCIENTIFIC REVOLUTIONS, Second Edition, University of Chicago Press, 1970.

[19] Sudnow, D., WAYS OF THE HAND, THE ORGANIZATION OF IMPROVISED CONDUCT, Harvard University Press, Cambridge, Massachusetts, 1978.

[20] Mintzberg, H., THE NATURE OF MANAGERIAL WORK, Harper and Row, New York, 1973.

[21] Dreyfus, H., WHAT COMPUTERS CAN'T DO, Revised Edition, Harper Colophon Books, Harper and Row, New York, 1979.

[22] Kotler, P., MARKETING MANAGEMENT, Fourth Edition, Prentice-Hall, Inc., Englewood, N. J., p. 322, 1980.

[23] Dreyfus, S. and H. Dreyfus, "The Scope, Limits, and Training Implications of Three Models of Aircraft Pilot Emergency Response Behavior," ORC 79-2, Operations Research Center, University of California, Berkeley (February 1979).

[24] Ostrovsky, Yu. I., HOLOGRAPHY AND ITS APPLICATION, Mir Publishers, Moscow (translated from Russian by G. Leib), p. 225, 1977.

[25] Goleman, D., "Holographic Memory: An Interview with Karl Pribram," Psychology Today, Vol. 12, No. 9, p. 80 (February 1979).

[26] Howard, R. A., "An Assessment of Decision Analysis," Operations Research, Vol. 28, No. 1, p. 13 (January-February 1980).

[27] Johnson-Laird, P. N. and P. C. Wason, "A Theoretical Analysis of Insight into a Reasoning Task, Postscript," in THINKING, edited by Johnson-Laird and Wason, Cambridge University Press, Cambridge, England, pp. 143-144 (1977).

[28] Ibid., p. 152.

[29] deGroot, A., THOUGHT AND CHOICE IN CHESS, Mouton, The Hague, The Netherlands, p. 308, 1965.

[30] Ibid., p. 308.

[31] Ibid., p. 309.

[32] deGroot, A., "Perception and Memory versus Thought: Some Old Ideas and Recent Findings," in PROBLEM SOLVING: RESEARCH, METHOD, AND THEORY, Kleinmuntz (ed.), p. 24 and 50, Wiley, 1966.

[33] deGroot, A., THOUGHT AND CHOICE IN CHESS, Mouton, The Hague, The Netherlands, p. 320, 1965.

[34] Ibid., p. 321.

[35] Kuhn, T., THE STRUCTURE OF SCIENTIFIC REVOLUTIONS, Second Edition, University of Chicago Press, p. 44, 1970.

[36] Ibid., p. 192.

[37] Ibid., p. 43.

[38] Ibid., p. 200.

[39] Heidegger, M., BEING AND TIME, Harper and Row, New York, 1962.

[40] Wittgenstein, L., PHILOSOPHICAL INVESTIGATIONS, Blackwell, Oxford, England, 1953.

[41] Merleau-Ponty, M., PHENOMENOLOGY OF PERCEPTION, Routledge and Kegan Paul, London, England, 1962.

[42] Mintzberg, H., THE NATURE OF MANAGERIAL WORK, Harper and Row, New York, p. 36, 1973.

[43] Ibid., p. 38.

[44] Ibid., p. 37.

[45] Ibid., p. 188.

[46] Ibid., p. 157.

[47] Brown, R., "Modeling Subsequent Acts for Decision Analysis," Technical Report, Decisions and Designs Inc., 7900 Westpark Drive, McLean, Va. 22101, p. 3 (July 1975).

[48] Mintzberg, H., THE NATURE OF MANAGERIAL WORK, Harper and Row, New York, p. 4, 1973.

[49] Brown, R., "Modeling Subsequent Acts for Decision Analysis," Technical Report, Decisions and Designs, Inc., 7900 Westpark Drive, McLean, Va. 22101, p. 12 (July 1975).

[50] Lindblom, C., "The Science of Muddling Through," Public Administration Review, Vol. 19, p. 82 (1959).

[51] Soelberg, P., "Unprogrammed Decision-Making," Industrial Management Review, Vol. 8, No. 2, p. 23 (Spring 1967).

[52] Hammond, K. and L. Adelman, "Science, Values and Human Judgment," Science Magazine, Vol. 194, No. 4263, p. 390 (October 22, 1976).

[53] Ibid., p. 392.