This thought experiment starts from the assumption that four degrees of prediction lie on a spectrum. Starting with absolute certainty, and progressing to complete uncertainty, that spectrum cycles back on itself to become a feedback loop: prediction breaks the rules of logic, paradoxically contradicting its "self." Zann Gill counterposes Lewis Mumford's question about linear projections, typical of future forecasting, with Ray Kurzweil's prediction in *The Singularity is Near* that accelerating feedback loops are converging toward Singularity.

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The Paradox of Prediction

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Are the arts and sciences two cultures or one? I will suggest that the arts and sciences are one culture to the extent that similar creative mental processes operate both in the formulation of hypotheses in science and in concept formation expressed through works of art. But they are two cultures, with an impassable rift between, when either attempts to explain (by its own methods alone) the operation of that inventive process in both fields.

A paradox is a logical progression that circles back to contradict one of its premises. This discussion loops on two levels: the *content* of prediction and the *concept* of prediction. I will describe how the *content* of the prediction can play an active role, influencing the events it predicts. The *concept* of prediction (meta-level) is subject to the same reflexivity. Although our progression in defining the four connotations will seem straight and logical, when the fourth connotation turns back to unhinge the absolute premises of the first, we realize that science and the arts are not opposite poles but rather on the same loop. Since defining is itself an "invention process," the fact that this definition reflects this characteristic should come as no surprise. The *paradox of prediction* underlies the process of invention.

In studies of the human mind and its invention process, those who would construct theories eventually arrive at a paradox when asked how the theory they have proposed predicts results that can be verified or refuted. This is why humanists study the invention process, but it remains a domain into which scientists seldom dare to venture. By gathering historical examples, observing or analyzing individuals whom society has termed "creative," the humanistic scholar can generalize from the evidence he has gathered, and perhaps formulate a hypothesis to predict how the human mind tackles creative problems. The method by which the humanist constructs his theory is clear. But when asked if he has done what any responsible scientist should do — provide his theory with means by which its predictive power can be verified and refuted — he is generally at a loss.

Nelson Goodman clarified the problem of prediction.

> The problem of the validity of judgments about the future or unknown cases arises, as Hume pointed out, because such judgments are neither reports of experience nor logical consequences of it. Predictions, of course, pertain to what has yet to be observed. . . . What has happened poses no logical restrictions on what will happen.[1]

Hume suggests that prediction accords with past regularity. Prediction-making, like invention itself, relies heavily on finding connections and making analogies, on the recognition of implied pattern. Following a linearly causal chain of inference is related to pattern recognition.

If a theory of invention were able to predict the results of that process, it would be verifiable (or refutable). Yet, the basic characteristic of the process is its ability to absorb accident, to resolve inconsistency, and to create with contingency, its intrinsic unpredictability. This is where the arts and sciences, by failing to recognize the paradox their two cultures have imposed upon each other, have been unable to define a coherent collaborative approach to the study of hypothesis construction or concept formation in either field.

EXPLANATION VERSUS PREDICTION

An explanation describes a phenomenon after the fact. A prediction, according to the traditional scientific connotation, characterizes a phenomenon such that its behavior can be anticipated *a priori*. Are explanations just the means by which we make predictions? Or is there a subtle difference? The complementary relation that both explanation and prediction share with contradiction is clear: a single counterexample to a theory will invalidate its explanation, cancel its prediction. But this does not prove that explanation and prediction are equivalent. In order to demonstrate that, one would have to agree that all explanations predict, and that all predictions explain. They do not.

Darwin's theory of the origin of species through variation and natural selection can be used to clarify the distinction between explanation and prediction. That theory explains the *selection criteria*[2] by which new species come about, but no scientist ever used it to predict the future evolution of novel creatures. However, when Australians used myxomatosis to control the rabbit population, Darwinian principles enabled forecasters to predict that a new strain of rabbits would become dominant with increased resistance to the disease. It did. Similar predictions of microorganisms' new resistance to antibiotics, for example, proved Darwin's theory of natural selection to be correct.[3] What is the distinction between the domain in which Darwin's theory could forecast successfully and that in which it could only explain after the fact?

In both cases, evolutionary development involved accident. But in the case of the rabbits and microorganisms, the type of accidents that would be selected and assimilated was known; nature's *local selection criteria* were established. In the case of new, unimagined creatures, criteria for selection were not established. The seemingly mysterious emergence of AIDS is an example. Knowing why such a disease can be selected for and why it survives helps us to know what it is and to predict its possible emergence. To the extent that *local selection criteria* can be established in a closed system, prediction of global structure is possible. This concurs with biologist Jacques Monod's thesis that the evolutionary development of the biosphere is compatible with first principles but not deducible from them. In other words, it is explicable but not predictable.

The example of Darwin's theory has illustrated the limitations of explanation for prediction. The limits of prediction *vis-à-vis* explanation are easily seen. The phases of the moon can be predicted without understanding how it rotates about the Earth or reflects the light of the Sun. The passage of the seasons was predicted long before its cause was understood, because men were able to recognize repeating patterns. So prediction does not imply an underlying explanation, though it does imply recognition of certain patterns — those relevant to the prediction.

It is generally agreed that, from a cognitive perspective, there is little difference between retrodiction (the reconstruction of the past), explanation, and prediction (the construction of the future), since all require completing the pattern implied by partial information. However, there is one difference: prediction points in the same direction as the arrow of time in evolution and thought. While we are moving away from the past events we attempt to retrodict or explain, we are moving toward the events we predict. So prediction has a temporal correlation with the process of invention, which retrodiction and explanation do not share.

Concern with rigor and accurate prediction has often pushed psychologists trying to understand human capacity for invention toward local experimental studies and away from the risk of global theory. Their small investigations often fail to converge; they remain isolated. The discipline of psychology has tended to focus its investigations on problems of detail, hypotheses that can be tested and verified.

Where prediction is expected, it is not surprising that experimental cognitive psychologists, wanting clear, indisputable results, tend to restrict their studies to circumscribed questions. Their experiments are closed systems; the open-ended system of mental inventiveness (with its inherent unpredictability) is ruled out. So the cognitive scientist can flash a little red light or an image to test his subject's reaction time, because this is measurable and predictable. The storage of an image requires microseconds and can be timed in the laboratory. Intellectual revolutions can be triggered by a small detail. Copernicus, in his investigation of discrepancies in the positions of the planets from their predicted positions, paved the way for the heliocentric hypothesis. Perhaps cognitive scientists' chronometric studies will surprise us with theoretical breakthroughs.

But creative problems have long histories, uncertain components, and unknown (i.e. unpredictable) results. That is why, though the scientist makes use of invention in hypothesis formulation and theory construction, he cannot study the process by scientific methods alone. For studies of mind, the two cultures, science and the arts, must become one again. The arts must respect the systematic methods of science. Science must respect the arts' acceptance of uncertainty and violation of control as important to concept formation.

THE FOUR FACES OF PREDICTION

The traditional use of the term prediction in physical science implies that prediction is both absolute and passive. But closer examination suggests that prediction has four connotations:

Absolute	(passive)
Probabilistic	(passive)
Possibilistic	(active)
Uncertain	(active)

The first connotation is associated with testing hypotheses and theories in the physical sciences: prediction is generally assumed to be *absolute* and *passive*. In physical sciences, ruled by absolute laws, a theory is tested, and possibly refuted, by finding a counterexample that contradicts the theory's prediction. The term "contradiction" is here not used in the strict logical sense — *p* cancelled by *not-p* — but rather in the sense Piaget termed "dialectic contradiction": a general statement or theory is contradicted by a single tiny false detail, or a particular counterexample. This is not the perfect dynamic equilibrium of logical contradiction; all parts of the theory may not be cancelled. But its validity as a whole is cancelled.

The task of a scientific theory is clear: it must explain; it may predict. In either case, it will be subjected to the traditional scientific test of verification through possible refutation. But this I suggest, in the case of theories that attempt to explain the process of invention, leads to a paradox. The demand that a scientific theory predict has been a stumbling block to any serious study of invention.

The second connotation of prediction is associated with the construction of rules in the biological sciences: it is *probabilistic* and *passive*. As Ernst Mayr has pointed out, seldom can biology boast the certainty of absolute laws. For this reason, prediction has a different meaning in biology from the physical sciences. While theory-building in the physical sciences generally demands that prediction anticipate with absolute accuracy, in biology its accuracy is usually statistical, rather than absolute; prediction may have different assigned levels of probability.[4] Evolutionary theory asserts the independence of prediction (*a priori*) and explanation (after the fact), forging a link between prediction and probability.

Prediction in both cases above is passive: an event predicted will come to pass (or not), independent of whether the prediction is made or not. It is assumed that the prediction is independent of the context observed, that it exerts no influence. Prediction also has an active connotation, which suggests that the fact of making the prediction may influence the outcome of future events.

The third connotation of prediction, here termed *possibilistic* and *active*, was historically associated with the prophetic arts. Today it is associated with “future forecasting” and the conceptual arts. The substitution of the term was deliberate on the part of those who did not want their possible scenarios to be mistaken for absolute predictions. Future forecasting derives much of its methodology from the statistical methods of the biological sciences. Its analytic aspect aims to be statistical, while its constructive, scenario-building aspect is more akin to the conceptual arts. Like biological prediction, future forecasting acknowledges the importance of contingency. But, unlike the general use of the term in biological science, here prediction is active; whether this fact is acknowledged or not, present forecasts become part of the database from which future forecasts are made. Both the prophetic and conceptual arts are concerned with revealing possibility.

Thus far, introducing the first three connotations of the term prediction has suggested a progression from absolute certainty in physical science to probability in the life sciences to possibilistic speculation in the arts. But this progression is an illusion; there is no such spectrum with physical silence sitting solidly at one end and the arts teetering speculatively on the other. The *paradox of prediction* lies in the circularity of our argument, through which science and the arts emerge not as two poles, but on the same loop.

The first connotation of prediction aimed to reveal pre-existent truth. The second and third connotations combined revelation with varying degrees of emergence (contingency that is unpredictable). The fourth connotation refers to emergence of something that did not pre-exist.

Marvin Minsky recounts that a famous mathematician, when warned that his proof would lead to a paradox if he took one more logical step, replied, “Ah, but I shall not take that step.” Minsky comments: “The consistency that Logic absolutely demands is otherwise usually available — and probably not even desirable! — because consistent systems are likely to be too weak. . . . I cannot state strongly enough any conviction that the preoccupation with consistency, so caluable for Mathematical Logic, has been incredibly destructive to those working on models of the human mind.” [5] C.S. Peirce would probably have agreed with Minsky. He felt that the terms deduction and induction did not cover adequately the mental activity of the creative scientist, who must make inferential leaps. He introduced a new term to account for this process: “abduction.” To paraphrase Peirce: The first stating of a hypothesis, whether as a simple question or with any degree of confidence, is an inferential leap that I propose to call “abduction.” Induction is the operation of testing the hypothesis; deduction proves that something must be a necessary consequence of the hypothesis. But it is abduction that makes the inferential leap and introduces a new idea. However man may have acquired his faculty of divining the ways of nature, it has certainly not been by a self-controlled critical logic. Man has a certain insight, which enables him to form correct hypotheses.[6] I argue that the inferential leap that introduces the new idea is akin to the fourth *uncertain, active* connotation of prediction: both are emergent processes.

In the first passive connotation, prediction and contradiction are complementary; in the second passive connotation, prediction and probability are complementary; in the third (active) connotation, prediction depends upon the interpretation of ambiguity; and in the fourth, prediction is emergent.

The fourth connotation of prediction is *uncertain* (emergent) and *active*. Our first connotation was the ideal class, prediction without qualification, perfectly pointing to future events. This fourth connotation is the null class, prediction unable to predict. Why do we need a null class? First, because it is here that the essentially unpredictable inferential leaps (sudden insights), which C.S. Peirce called “abduction” belong. Second, the null class is necessary to show the fundamentally paradoxical nature of the concept of prediction itself; this null class loops back to contradict the perfection of the ideal class. Finally, this fourth connotation clarifies the link between the concept of prediction and the process of invention I shall sketch.

A general theory predicts (either absolutely or probabilistically) the behavior of phenomena in the specific instances it covers. But when one instance contradicts the prediction, the theory must be abandoned or transformed to take account of this larger context. So contradiction and contingency make constant demands on prediction, transforming it from passive to active. Interpretation molds it; emergence extends it. Prediction seen in this way is no longer a static “thing,” but an evolving model, a representation of our understanding. Though prediction implies looking ahead, a theory is an explanation based on our understanding now; what it predicts for the future depends upon what we understand in the present.

Realizing that we can only act, think, predict, or invent in the present is critical to understanding the characteristics of invention. The distinction between prediction (*a priori*) and explanation (after the fact) is related to a further distinction between *selection criteria* and *goals*. Explanation operates in the present, as do *selection criteria*, patterning information that is currently available. Prediction and goal-setting attempt (with the partial information of the present) to construct models of the future.

We like to think absolute control characterizes the scientific method. But absolute control rules out uncertainty, and questions. Envisage creative discovery and invention as a camper searching for a box of matches with a flashlight in the dark. When he is in perfect control (i.e., immediately able to shine the flashlight directly on the object of his search), we know he didn’t need to find it. He already knew where it was. In all other cases his question is, “Where could my matches *possibly* be?” The camper’s flashlight must hit the object by accident, enabling him to *recognize* it. But the camper poses his questions (shines the flashlight) selectively, choosing categories of accidents that have promise. He doesn’t shine his flashlight in the trees if he recalls that he left his matches on the ground.

To demand that a theory of invention predict the path, or results, of that process is unreasonable for the same reason that setting goals for the creative aspect of the process is impossible. If the process is creative, it must be able to discover or invent something not anticipated in advance. If you can state clearly what you'll invent, the creative challenge is to figure out *how*. Stating the aspect to be invented as a goal implies creating a construct that (in the present) you don't have information or tools to construct. You can't construct it. To avoid semantic confusion, note that in the case of the camper, his goal should be stated not as "finding the box of matches" but rather as "finding *the location* of the box of matches." The location is what he does not know, and cannot state, until he finds it. He uses *selection criteria* to pose plausible questions to the problem context, hoping through the combination of plausible questions and accident to find his matches. Through his sequence of questions, he ambushes his object by eliminating possibilities until he finally hits on the correct answer. This simplified analogy could be misleading: the camper operates only through a process of elimination; he will receive only "no" answers to his questions, until a "yes" reveals the matches.

Our first passive connotations of prediction say: If this . . . . then (certainly or probably) that. The challenge of science is to predict what has hitherto been unpredictable. Thus far, we've considered the ability of prediction to specify what is, or is not, going to happen (with absolute certainty or with some degree of probability). I described the complementary relationship between prediction and contradiction. The two passive connotations of prediction are generally taken to cover the meaning of the term. But drawing a correlation between the concept of prediction and the process of invention reveals the two active connotations of prediction, first as possibilistic and second as uncertain (emergent).

PREDICTION AND POSSIBILITY

The third connotation of prediction introduced the *active* interpretation of ambiguity. Exploring how prediction molds possibility emphasizes that the concept of prediction changed as the rift between the arts and sciences widened in the technological era. Prediction, as used in science, implies that the successful theory must predict *precise* testable results (whether absolute or quantitatively probabilistic). But before the scientific era, prediction correlated, not with precision, but with vision. The great prophets of the Old and New Testament didn't simply foresee future events. They studied the traditions of the past and the conditions of the present in order *to recognize* possibility.

Prophets constructively used prediction to say: If this. . . then possibly this. Through ambiguity, prediction suggested alternative possibilities, calling on people to recognize patterns emerging from present low levels of coherence. The prophets urged men to prepare, to avert disaster. So their prophecies were not fixed and foreordained; they addressed their listeners as free and responsible individuals, who could design their future. The desire to teach, rather than merely predict, moulded their prophecies. They were men of vision — "seers."

Their attention focused on the present evolving toward a future, which humanity could guide toward different alternatives. They were critics of society, revolutionaries; often they were leaders. The prophet, as Max Weber adapted the term for our day, is concerned with critical appraisal of his society in light of what he believes to be his society's fundamental values, its "self." The Hebrew prophets did more than denounce corruption. The prophet Ezekiel, during the Babyonian exile, developed a vast program for the reconstruction of the state of Israel (Ch 40– 48). Though his program was never realized, its vision did much to preserve the spirit and unity of the community in exile. For the seer, prediction differed from its connotation in the domain of science: it might be precise or ambiguous; the important point was that it should influence the course of events constructively. The prophet recognized many creative ways to influence events: the artistic statement, the powerful idea, the model that envisions, the warning that motivates. He saw how small deviations might become triggers to major changes, unfocused patterns that might, through successive approximation, converge toward coherence.

Plato speaks of the "prophetic madness" of the Pythia (the priestesses), from which insight emerged. A famous (though possibly apocryphal) prediction of the oracle at Delphi, recounted forty years later by Herodotus, illustrates the potential open-endedness of prediction, used not as a scientific, but as a creative tool. During the Persian Wars, when worried Athenians asked the Oracle for guidance, the Oracle told them to trust "the wooden wall." Herodotus relates how everyone had a different idea of what this message meant. Old men thought Apollo meant to tell them the Acropolis, which was defended by a wooden wall, would be safe. Others believed the god referred to the "wooden wall" of the ships, which should be made ready. Of the group that thought he referred to the ships, some thought they should sail away to a new land without fighting, while others (including Themistocles) thought they should wage a sea battle. This last is what they did, destroying Xerxes' fleet at Salamis in one of the great battles of history.

The role of the Oracle here was not to give a single answer, but to motivate a thought process from which a number of alternatives emerged. Ambiguity, contradiction, and conflict played important roles in that constructive process. "Wooden wall" could be the attribute of several constructs, palisade or ships. Depending upon the framework within which it was viewed, it had a variety of meanings. The prophetic challenge was to determine the appropriate framework (pattern) for its interpretation. The ambiguity (open-ended possibility) in the prediction was resolved through interpretation.[7] So, often, successful "prediction" relied not on the assumption of static stability in the course of events, but rather on the dynamics of interpretation. It took the form that emergence takes in the creative process, relying on instability, on ambiguity, contradiction, and conflict. By taking a parallel form, it allowed the image of the future to emerge through a parallel process.[8]

To recognize future patterns in present conditions is a consummate challenge. Humanists, looking at history and biography for insight into the mind's invention process, must accept the predictive limitations of their method. Lewis Mumford appropriately pointed out that an objective observer in Rome in the third century A.D. might well have predicted, looking at the imperial public works program, an increase in the number of public baths, gladiatorial arenas, garrison towns, and aqueducts. In fact, within three centuries the frontier garrisons were withdrawn, the Roman baths were closed, and some great Roman buildings were being used, either as Christian churches, or as quarries for new structures. Can anyone, asks Mumford, recalling this historic transformation, insist that the rate of scientific and technological change must accelerate indefinitely or that technological civilization will absorb all the energies of life for its own narrow purposes, profit and power?[9]

Ray Kurzweil in *The Singularity is Near* counters Mumford with an equally provocative question: An accelerating rate of technological change has been clearly observed, but there is no certainty about how such change will impact civilization and life in the future. How will we respond to Kurzweil's prediction of the Singularity (when machines exceed human intelligence), marshaling creativity as the Greeks did in their interpretations of the Oracle, so that we can constructively mold the future as we continually accelerate our pace of change?[10]

UNCERTAINTY AND EMERGENCE

The fourth connotation further emphasizes prediction's active role: it not only interprets; it may also construct. Prediction is linked with emergence, precisely because of the *paradox of prediction*: the uncertainty inherent in observation means that any prediction (which the observer attempts to verify) will influence the observation. So the *paradox of prediction* warns us: a theory may predict, but the experiment that would confirm or refute that prediction may also be influenced by the prediction itself. The expectation of total objectivity is unrealistic. While those who would like to believe in universal applicability of the "scientific method" may find this lack of objectivity disquieting, those ready to accept that understanding may come also through a "constructive" paradigm akin to the arts will not be discouraged. It's time to recognize that reflexivity, an anathema to traditional science based upon linear progression, has a role to play in the theoretical (as well as practical) construction of future possibility.

The connection of this fourth connotation of prediction with invention is not coincidental; both are expressions of thought and share its characteristic emergence and reflexivity with evolutionary biology. The intrinsic unpredictability of invention, both in the individual and in the evolution of cultures, is clarified by Jacques Monod's distinction in biology between "emergence" (of something wholly new) and "revelation" (of something that existed but had not before been perceived): For those who regard evolution as the majestic unfolding of a program woven into the fabric of the universe, "evolution is not really creation but uniquely the revelation of nature's hitherto unexpressed designs. Hence the tendency to see in embryonic development an emergence of the same kind as evolutionary emergence. According to modern theory, the idea of revelation applies to epigenetic development [of a single organism], but not of course to evolutionary emergence, which, owing precisely to the fact that it arises from the essentially unforeseeable, is the creation of absolute newness."[11]

Monod's distinction between "revelation" and "emergence," while useful, is not so clear with respect to creative processes as he makes it with respect to biology. The concept of possibility is slippery at best. Prediction concerns possibility. Whether pre-existent possibility is revealed or whether it emerges, possibility by definition always "exists" if it can be stated as a possibility. So, while Monod's distinction is important for biology, we shall find that, in the invention process, it is generally blurred, since prediction does not serve as a reliable criterion for making the distinction. Mathematician Jacques Hadamard would probably relate Monod's distinction to his own between discovery (the "revelation" of something that had not before been perceived) and "invention" (the "emergence" of something new). Hadamard differentiates discovery from invention: "Discovery concerns a phenomenon, a law, a being which already existed but had not been perceived. Columbus discovered America: it existed before him; on the contrary, Franklin invented the lightening rod: before him there had never been any lightening rod."[12] So Hadamard might say that discovery is "revelation," while invention is "emergence" of something wholly new.

Invention and discovery possibly lie on two sides of a continuum, with great creative accomplishments in both the arts and sciences falling in between. A great work of art, though an invention of the artist, taps into fundamental laws of human nature and the universe, which existed before and will exist after the artist has passed. Similarly, any great scientific "invention," including Franklin's lightning rod, taps into fundamental laws that already exist. Both reveal possibility that was always there. Both teach us something new about ourselves and the world.

Possibility "emerges" as a recognizable figure from the confused ground of unrealized possibility, possibility "revealed" by discovery and invention. Emergence describes what occurs; revelation describes our perception of what occurs.

The challenge of science is to explain or predict what has hitherto been unexplainable and unpredictable. The challenge of the arts is to work creatively with mystery and unpredictability, while the great challenge of both the arts and sciences is to bring these two domains of exploration together so we can better understand the creativity of the human mind.

Several games and an evolutionary metaphor exemplify how invention harnesses the *paradox of prediction*. I'll use the game of Twenty Questions to distinguish between pre-existent revelation (the passive connotation of prediction) and emergence constructed through participation (the active connotation of prediction). I'll then use the game of chess to distinguish between the path-oriented notion of prediction, having its basis in a causal chain of inference and the emergent notion of prediction constructed through pattern completion by making inferential leaps. These inferential leaps could not have been made *a priori* because the state from which the leap was to be made still had to be constructed. Finally, drawing on the ideas about the games of Twenty Questions and chess, I'll outline the characteristics of an invention process, breaking from the traditional goal-oriented paradigm for problem-solving, positing instead that successive approximation underlies human pattern recognition and evolutionary emergence.

THE GAME OF TWENTY QUESTIONS

Playing the game of Twenty Questions entails more complex dynamics than being a camper trying to find his matches, because the game operates with both "no" (elimination) and "yes" (selection). The Respondent thinks of something anything. In twenty questions or less, which must be phrased so they can be answered by "Yes" or "No," the Questioner tries to close in on that object, to identify what the Respondent has in mind. It may be a toy, a tree, a fictional character, a historical event. The three questions most players start with are, "Is it an animal? A vegetable? Or a mineral?" but those three would not help to find a historical event, for example. What is surprising to the new player is the rapidity with which, starting with infinite degrees of freedom (all is possible), the Questioner, through systematic questioning, eliminates categories to "ambush" the object. In this game a "no" answer is as useful as a "yes." Both serve equally as guides.

The game of Twenty Questions bears analogy to nature's creative process of biological evolution. A "yes" answer to a question says: "Continue that path of questioning." "No" says: "That's the wrong path; try another question." The birth of a new organism is a question posed by evolution to its environmental context. If the organism survives to reproduce, the environment has said, "Yes, that idea fits well enough to merit developing in this context." If it dies before reproducing, the environment has said, "Let's not try that again. Ask me a different question." The game models a digital search process that attempts to find its "object" by the most efficient path or line of questioning. Note one difference between the game and biological evolution. Twenty Questions is digital; the answers will be absolute: "yes" or "no." Nature's answers in the evolutionary process are analog, since they may fall anywhere on the spectrum between "yes" and "no." Digital systems are self-contained, and so are precise and verifiable because their operations are discrete, rather than continuous. Analog models, on the other hand, lack this ideal accuracy, because they simulate ranges that are continuous. To the organism the environment does not just say, "No, you will not survive to reproduce," or "Yes, you will reproduce." Some organisms may reproduce more or less than others. "Differential rate of reproduction" computes in subtle ways nature's evolutionary directions. In an analog process there is possibility of incremental error, which correlates with possibility for transitional change.

In our analogy the Questioner is the creative problem-solver. The Respondent plays the role of the environment or context, which accepts or rejects each creative act (each question). The context that a creative problem addresses determines the appropriate form for its resolution. The Questioner starts with unbounded ground, the "enormous space" of Heraclitean consciousness whose boundaries have yet to be located. The entire universe is his context, and, from that universe of possibility, he must pick out the one figure (object) of his search. He doesn't know his "object" in advance, so, initially, figure and ground are confounded. The challenge of the game is to separate figure from ground. Gradually, what was undifferentiated (the contextual ground of the problem) is differentiated and as figure emerges from ground.

Like the camper searching for a box of matches in the dark, the Questioner in Twenty Questions hopes accidently to hit the right path, the right line of questioning. He has no answer when he starts to search, but he selects categories in which he'll try his luck, aware of the overall frame defined by the questions already asked and the answers already received.

The game of Twenty Questions highlights two key points implicit in the idea that *selection criteria* and accident together produced the striking products of evolution and human creative ingenuity. One tends to assume that the number of questions in the game is arbitrary. But suppose there were fifteen questions in the game? Or thirty? Why *twenty* questions? [13] If there were fifteen, the Questioner would have to make larger inferential leaps to find the solution in fewer questions. He would have to be luckier in his choices of questions. If there were thirty questions, there would be so much information that he would need far less luck to find "it." So our first point: implicit in the combination of *selection criteria* with accident is intuition, which links them. The camper looking for his matches, the Questioner choosing his questions, the Scientist or Inventor following his hunch are "lucky" in part because of intuition. There are some who say that nature's evolutionary process is also directed by more than mechanism — that the universe possesses something akin to "intuition." It is intuition that enables the scientist to make the inferential leaps that C.S. Peirce called "abduction." Intuition connects decisions (and *selection criteria*) with happy accidents. And intuition guides the formulation of prediction, which is itself is an inferential leap.

Our second point implicit in the combination of *selection criteria* with accident may seem, in comparison with the first, mundane. It's evident when we ask, "Why twenty, rather than fifteen or thirty questions?" First, the size of the inferential leap prescribes how much intuition is needed. And second, the size of the base from which the leap is made; a vast amount of information is generated by 2^{20}, enough that in jumps of a reasonable size the normal person with average intuition can "make it" in twenty questions, whereas fifteen questions may not give the Questioner enough raw material (in this case, patterned information) to construct his hypothesis.

Twenty Questions illustrates neither creation nor *emergence,* but *revelation* of the hidden object, like pattern recognition in the creative process. Pattern *recognition* and *revelation* are constituents of invention, artistic and scientific discovery — all processes that reveal possibility. But emergence participates as well. The distinction between emergence and revelation for Monod is determined by predictability. If we assert that all emergence (while perhaps unpredictable) is *recognition* and *revelation* of pre-existent "possibility," we obliterate the distinction. Where "possible" though, it's useful to distinguish between what is predictable and what is not.

The game of Twenty Questions is solved when the object is "revealed" in the Respondent's mind. Was that revelation predictable? What the Questioner must discover to succeed was programmed before he began questioning. What Monod meant by "predictability," was not whether it is possible to predict, but whether there was a pre-existent program or "right answer."

A POSSIBLE QUESTION, A QUESTION OF POSSIBILITY

You cannot play Twenty Questions with nature and win because nature doesn't have the answer. Nature never decides in advance what to evolve; it's a step-by-step invention process that nobody can predict. Similarly, any creative actor establishes systematic *selection criteria* to interpret the responses to possible questions and then "plays out the game" according to those criteria. Though he may decide to revise them based on what he learns in process, he doesn't know the precise goal (end result) in advance.[14]

Suppose that our Respondent, like nature, had not thought of anything before the Questioner began to ask his questions. What then? He'd have to answer each question by "yes" or "no." For the first question he could arbitrarily pick "yes" or "no." His answer to the second would need only to be consistent with the first. For each answer be consistent with all previous answers dictates that the game must converge by successive approximation toward an object that neither the Questioner nor the Respondent could have *predicted* in advance, illustrating what Monod called *emergence*. This object would be defined as necessary by the sequence of questions or moves that converged to it. So the object of the Questioner's search would not be absolutely defined until the last question made it the necessary unique object of that path.[15] Not until it existed as the object could it be unquestionably predictable as such.

Twenty Questions is a metaphor for Kurzweil's prediction of convergence toward "Singularity" (a singular point in time when machines exceed human intelligence) ; each question, or new technology, increases our acceleration toward that vortex.[16]

In the original version of Twenty Questions, the right answer existed regardless of which questions the Questioner chose to ask. That version of the game is analogous to passive prediction where an event will come to pass regardless of whether it is predicted or not. In this new version of the game the answer did not exist *a priori*. It was created by means of the questions asked. Each question, together with its response, becomes part of the database from which new questions are constructed. This version is analogous to active prediction, since the Questioner, by her choice of questions, and the Respondent, by her selection of answers, together create the Word. It didn't exist (and could not have been predicted) until they created it.

But would the Questioner ever reach that final question, the question that would tell him he had arrived? If he had a limit of twenty questions, then the twentieth would be "it," if consistent with the previous nineteen *and* if the Respondent were generous enough to concede. But when there is no twenty question limit, the game, if played without any preformulated answer, will, like nature's evolutionary process and man's creative work, never end.[17] There will never be a final answer from which one cannot pose yet another question: there will always be a *possible question* and a question of possibility.

Many scientists have tried to reconcile the implications of the Uncertainty Principle with classical physics by asserting that the observations existed *a priori*; it was simply the process of measurement that disturbed them,[18] an analogy to the original game of Twenty Questions. Classical science would be only moderately disturbed by our inability to observe what we could theoretically predict. But the problem is deeper; it is not the old "revelation" game of Twenty Questions that we're playing, but a new "emergence" game. Those results did not pre-exist.

The *paradox of prediction* warned us: where discovery reveals pre-existent patterns in a closed system, prediction is possible. But in an open system, invention is an "emergence" game. Prediction of its results is impossible. Does that imply that no model of the process can be constructed? No. What it implies is that objective detachment is impossible. A model of the invention process must itself be "invented" by the method it seeks to describe. Circularity is unavoidable.

I have focused on the distinction between revealing a pre-existent solution and emergence (or invention) of a new solution through successive approximation. In Twenty Question there's not only a path of questions (a sequence of choices and actions) but also a frame, evolving gradually from incoherence (any solution is possible), to coherence and focus (this solution is "it") through pattern recognition. The causal chain of questions relates to the goal-oriented paradigm of problem-solving, to decision trees and to linear progression. Gradual pattern completion relates to the evolutionary paradigm of emergence through successive approximation. Both of these complementary dynamics operate in the game of Twenty Questions, but they are more visible in chess.

THE GAME OF CHESS

Like Twenty Questions, chess is played one move at a time. Although strategies may be planned, each strategy is subject to change as situations emerge that were not predicted.

Chess is like invention, since its possibilities are open-ended — unpredictable. The form that checkmate will take cannot be predicted before the game begins, nor determined with the first move. But with each successive move it is progressively more and more determined until finally, with the last move, checkmate (final state or frame of the game) is completely defined. By applying his *selection criteria* (the rules of the game and his personal approach to playing the game), the chess player lets precise definition of his goal, checkmate, evolve through the game, just as a painting is only finally defined with the last brushstroke. As Piet Hein said, "The work of art solves a problem which we could formulate until it was solved."

This analogy is both similar to, and different from, the creative process. Chess sheds light on why *twenty* questions. A process is predictable to the extent that its domain is circumscribed. So, though we cannot predict at the outset of the game which form checkmate will take, we can conceive alternative possible forms. Relative predictability exists because chess is a relatively circumscribed domain.

In artificial intelligence a tendency to analyze and mimic rather than to synthesize and reconstruct was the shortcoming of early attempts to design chess-playing computer programs, which led to better understanding of how the human mind functions. Whereas before, students of the human mind tried in various ways to analyze it (by scientific methods), designing computer software tried to synthesize mental skills, and showed that chess-playing demands conceptual, artistic skills. The long AI chess effort showed greater understanding occurs, not through analysis alone, but when analysis is applied to problems requiring creative synthesis.

The human programmer designing a chess-playing program designs the program in advance, after which the chess-playing computer is "on its own" to win or lose the game. Just as genetic endowment produces an organism that will then survive to reproduce or not, so the programmer cannot anticipate the billions of possible combinations of moves that could come up in a game of chess. The best he can do is teach the computer the rules of play, give it *selection criteria* so that, whatever configuration comes up, it can apply those criteria and decide. Determining the necessary *selection criteria* was a great challenge for those designing computer programs to play chess.[19]

Estimates suggest that a human world champion chess player can hold a maximum of 50,000 patterns in his head. Early chess-playing computer programs, Belle and Blitz, could consider ten times that number. But not until Big Blue did a computer program beat a human chess champion. For chess program designers the challenge of this problem raised an obvious question: Although the computer had tremendous computational advantage, why did the human still win?

Perhaps the way we think we think is not really how we think? The early computer programs, whose artificial intelligence was modeled on the way we thought we thought, were playing chess differently from the human chess champions.

Designers of computer chess programs started with the assumption that superior ability *to predict* how alternative scenarios (paths) in the game would play out would give the computer tremendous advantage over the human player. They were surprised to discover that it didn't. In fact, it "confused" the computer; every move in the game changed the board; the computer started over again to try to compute (i.e. "predict") all the new alternatives. Human pattern recognition and strategic patterning capabilities outwitted the computer.[20]

Experts analyzing this difference between the way a computer and human play chess hypothesize that the human player perceives the total pattern of the game at any given moment as a *Gestalt* (a frame), almost the way we recognize a face or a familiar neighborhood. Face and pattern recognition are considered synthetic (right brain) activities, suggesting that both right and left-brain functions must operate together to win the game. The perception of *Gestalt* is a perception of now.

As the game evolves, the human chess champion *generates* his strategy in the present. He *recognizes* patterns evolving. The problem for him is one of "coherence" — total pattern recognition and development. He's working not only with his linear sequence of moves but also with the global pattern of the chessboard. He's not primarily predicting; he is actively constructing. He's not jumping ahead to conceive future goals; he's working with present emergent patterns.

The computer, on the other hand, despite superior ability to race ahead to compute future implications of alternative move sequences or paths (analytical function), tended to get distracted by every little change in the context of the game, to fail to structure a consistent strategy. For the computer, the process is solely analytic; perception of *Gestalt* is the province of the human. *Patterning* in the present, rather than *predicting* future alternatives, seems to be more important to winning the game. This draws simultaneously on right and left brain skills, demanding *recognition* of *coherence* in patterns emerging.

I'll next outline how the process of invention relates to the *paradox of prediction* and to the two games we have just discussed.

SUCCESSIVE APPROXIMATION THROUGH PERCEIVING DIFFERENCES

Traditional problem-solving models would say that the problem-solver looks at the present unsatisfactory state, compares the present state with a goal state, which he's already clearly defined, perceives the *difference* between the present state (chaotic) and the goal state (dearly organized), and tries to reduce the difference. Fairly straightforward. We tend to confuse this "match present state with goal state" problem-solving with invention (which involves the gradual emergence and definition of the goal state). We neglect that the two processes are totally distinct. The creative processes of hypothesis construction in science and concept formation in the arts begin with the uncertainty of "not knowing," asking questions to gradually, through a series of questions, ambushes their object. Neither can state its goal, until it has created it. The goal is the hypothesis or concept that the process seeks to create.

Minsky, referring to Charles Babbage's original use of the term in 1822, calls machines that mimic goal-directed behavior "Difference Engines," since they must contain a description of the goal state and be able to recognize the various differences between present state and goal state. The "Difference Engine" integrated by finding differences in data, differences between differences (and so on), and extrapolating. Difference-engines are conceptually related to the "General Problem Solvers" investigated by Newell, Shaw, and Simon in the late 1950s.[21] But recognition of differences doesn't pre-suppose goals. Recognition of differences is merely necessary to apply *selection critera.* So the "Difference Engine" could chug along without ever applying its skills to contrast present state with goal state by merely applying them to contrast present state with next state in order to choose what to do now at this moment of decision-making.

The notion of *iteration* and *successive approximation* can then be applied not to "reducing the difference between the present state and the goal state" but to "reducing the difference between present state and next state." By coherence-seeking (comparing the present unresolved state with a possible more resolved next state), the process successively approximates its goal. Goals (future, as yet not revealed) relate to objects, and to the problem of prediction. *Selection criteria* (present), on the other hand, relate to the process whose goal, in an open system, is inherently unpredictable.

Starting from a "confused" initial condition, through the alternation of accident with assimilation, pattern gradually reveals its "self." The inventor needs the so-called (goal-directed) "Difference Engine," not to perceive the difference between present state and "goal state," in order to match the two, but to see the difference between present state and *possible* "next states," in order to apply his *selection criteria* to ask the next question. The next response will enable the engine to decide what to do next. So the Difference Engine chugs from frame to frame, from this state to the next in the problem-solving process. It's a local train that must stop at every station. At each station it frames another question, "Wherefrom? Whereto?" to arrive at its destination.[22] These also, not coincidentally, are the questions of free association as the mental stream of consciousness flows (or chugs) from one thought to the next.

Consider a game related to the game of Twenty Questions, but simpler. A child looking for an Easter egg hears his parents say "you're getting warmer" or "cooler," so he knows whether he's moving in the right or the wrong direction. The scientist, artist, or inventor has a subtler challenge to recognize reinforcing or inhibiting signals that tell him he's moving toward or away from a successful result. His definition of "successful result" (i.e., his goal) may evolve and become gradually clearer in process (i.e., nobody hid that Easter egg in advance).

The response ("you're getting warmer; keep heading this way and you'll find the golden egg" or "you're off track, try a different tack") is the positive/negative feedback that guides the process. Based on that response, whether positive or negative, you decide whether to maintain or change your next moves. And you also decide whether to maintain or change your *selection criteria*. So selection criteria are not static rules. In the game the player can change his criteria as he observes the effects of every move.

CONSTRUCTION AND COHERENCE-SEEKING

The ability to see the pattern of the chessboard as a whole (as a frame) is necessary to seek coherence, which refers to an underlying pattern or structure of elements. The term is used to describe human or artificial intelligence pattern recognition. Perception of coherence can fill out the details of an ill-defined concept so resolution can gradually emerge. Ability to perceive "coherence" demands synthesis, to perceive implied structure and "fill in the blanks." The complementary skill of the analyst is classification, which takes apart.

Coherence describes not only visible, organizational and conceptual patterns, but also functional systems. Coherent systems are characterized as non-rigid, evolving structures. An institution, community, city, or ecosystem, if it has the flexibility to operate and adapt to change, is coherent. Through perception of coherence "educated guesses" are based. Speculation requires imagining connections that may not be verifiable, recognizing structure only partially suggested, perceiving pattern implied by partial information, and filling in what is missing.

Michel Foucault refers to the "law of coherence as a heuristic rule": the notion that where contradiction arises in the history of ideas a higher unity [a new frame] is sought to restore coherence.[23] This is the word that E.T. Owen uses to describe Oedipus' final revelation of his identity; "He is overwhelmed by a sudden flashing into complete and terrible coherence, of all the disjointed intimations of the past. . . ."[24] The final frame (fate) or goal of this process is only clear when the final clue is in. When the final move has been made, the form of checkmate is revealed. And the quarry is the King, Oedipus himself.

In describing the creative process of hypothesis construction or concept formation we tend to seek something for the process to refer back to (an innate structure) or forward to (a goal). But suppose there's no fixity to which structuration can refer (no innate structures and no goals). Such total relativity is intuitively abhorrent. But is it possible? I propose that coherence-seeking, since coherence is a characteristic, not a structure, substitutes relativity for fixity, providing a basis for the hypothesis of "successive approximation" to occur as invention moves forward.

Problem-solving can proceed without a referent (an innate structure to refer back to or a goal to refer forward to) by referring iteratively to itself, comparing each present step with a possible next step which is recognized through coherence-seeking.

To identify and categorize depends upon the ability to generalize. If we generalize back far enough we arrive at the types of primitive structures that Kant, Chomsky, and others described as innate. Reversing direction, the ability to construct and specify depends upon coherence-seeking.[25] Generalization and specification lie on opposite sides of one continuum. Generalization drives back to innate, unspecified structures, while coherence-seeking drives forward to construct and differentiate new, specific structures. If invention lies on this continuum, it must require both innate structures and a constructive, coherence-seeking method.

Coherence-seeking completes a pattern only partially specified. So the hypothesis of innate structures ties in with the premise of a constructive process based on coherence-seeking in the following way. Imagine that continuum as a vortex. On the outside are generalized innate structures. On the inside, as dynamics converge, are specified particular structures (e.g., specific hypotheses and concepts). Converging from outside to in, the process of construction focuses and specifies, from general (lack of differentiation) to specific. Inferential leaps specify and fill in the pattern that specification implies.

Coherence-seeking presumes ability to reverse that process, i.e., to differentiate into categories and to generalize, though I have not stated that the transformation process itself is reversible (frequently it isn't). Rather, an individual's ability to conceive, construct, and guide a process that converges toward an unpredicted outcome) is dependent upon the complementary ability to generalize and analyze.

Coherence enables successive approximation through iteration and gradual recognition relies. If we diagram the three related hypotheses of how concept formation takes place as three vertices of a triangle, we might label one vertex "innate structures" and the second vertex "goals." The third vertex would be labeled "coherence." The process may refer back to innate structures (Chomsky et al.) or forward to goals (Piaget et al.) or, as I have proposed, it may, through coherence-seeking (in process), refer to its "self," from present state to next state, through gradual and successive approximation. All three explanations rely on a referent and on the ability to compare. I suggest that each has a partial explanatory role to play; the acceptance of one explanation as plausible does not preclude accepting one or both of the others.

Whether innate mental structures (e.g., a universal template for language) exist that are later filled in with specific content, or whether schema are constructed, the question remains of how this is accomplished. I have suggested that we naturally seek *coherence*, an attribute of both objects and processes but is neither itself.

THE CONCEPT OF EVOLUTION, THE EVOLUTION OF CONCEPTS

The evolution of the concept of "evolution" illustrates emergence through coherence-seeking. The quasi-evolutionism of eighteenth-century thinkers laid the conceptual foundations for Darwin's insight. Naturalist Georges Buffon wondered if the ass and the horse might have been descended from a single ancestor. Mathematician Pierre-Louis Maupertius imagined in 1751 that species might multiply due to the fortuitous recombination of particles of elementary organisms. Philosopher Denis Diderot postulated in 1753 one primeval, prototypical animal. And Linneas by 1760 admitted that species could vary. Darwin recounts how "in October 1838, that is, fifteen months after I had begun my systematic inquiry, I happened to read for amusement Malthus on *Population*, and, being well prepared to appreciate the struggle for existence which everywhere goes on . . . , it at once struck me that under these circumstances favourable variations would tend to be preserved and unfavourable ones to be destroyed. The result of this would be the formation of new species."[26] So thinking about the law of population (and the problem of overpopulation) led Darwin to wonder, "What processes act to control population explosion?" and inspired his hypothesis of transformability of species through natural selection. Darwin, in the first five editions of the *Origin of Species*, did not use the term "evolution"; his intention was instead to show that species are modified over time by natural selection. Even the expression "survival of the fittest," later so important in evolutionary theory, did not appear in the first edition of the *Origin of Species*. Instead Darwin spoke of "descent" and "natural selection." Thirteen years later Darwin referred to "the great principle of evolution,"[27] which was implied at the outset, though it took time for Darwin and others (notably Herbert Spencer) to *recognize* it as the completion that the conceptual pattern suggested.

In Darwin's formulation of his principle of "survival of the fittest," *selection criteria* lie in the environment, not in the process because his model focused on organisms as "objects," ruling out the role of behavior (the organism's decision-making apparatus). I've suggested that criteria lie both in the individual's organism's creative process (through which he interprets and acts on feedback from the environment) and in the environment.

The Duke of Argyll recalled a conversation he had with Darwin in1882, the last year of Darwin's life: "In the course of that conversation I said to Mr. Darwin, with reference to some of his own remarkable work on *The Fertilisation of Orchids* and upon *The Earthworms* and various other observations he made of the wonderful contrivances for certain purposes in nature — I said it was impossible to look at these without seeing that they were in effect an expression of mind. I shall never forget Mr. Darwin's answer. He looked at me very hard and said, 'Well, that often comes over me with overwhelming force; but at other times,' and he shook his head vaguely, 'it seems to go away.'" Etienne Gilson wondered if Darwin saw that astonishing inventions in nature were "the effect and expression of an elementary form of thought, or of a force related to thought, but because the evidence gave no purchase to demonstration, he turned his concerns away from it."[28]

I have shown a correlation between invention (whether biological or human) and thought. Two distinctions must be made between closed and open systems. First, cognitive scientists often argue that the cognitive process is the same, whether you're reinventing the wheel (assuming that you've never seen a wheel before) or inventing something new. Second, many also argue that the process is the same, whether the results are predictable or not. According to this argument, a sufficiently rich and complex system, such as number theory, will demand the same creative ingenuity to develop as a novel invention, even though its theorems are entirely predicted by its axioms. In the game of Twenty Questions the Questioner's cognitive process will be the same, regardless of whether there is a pre-existent right answer or not. True, in the simplified world of the game.

But the problem is subtle, and goes to the heart of questions in artificial intelligence. I argue that there is a distinction between invention in a closed system (a problem for which an answer exists *a priori*) and in an open system where new inconsistent, unpredicted information can be assimilated. That distinction points to the core of my argument. In a closed system the rules cannot change. In an open system they may.

The process of invention entails more than simply filling out implied pattern. It entails making (and breaking) the rules by which pattern is constructed and selected. So it's not only the unpredictability of events, but also the unpredictability of the inventor (the possibility that he may change the rules of his game) that characterizes invention and links it with the arts. We cannot deny the important role inconsistency and contradiction play in this process.

Summarizing the passive and active connotations of prediction: the passive connotations were based on the misperception that the so-called "scientific method" is a totally controlled process. The active connotations were traditionally based in the prophetic (sometimes mad) insights of the arts, but recently find place in the equally "maddening" insights of science. The "scientific method" assumes that theories must reliably (and passively) predict something, but it cannot construct the theory that will predict how theories will be constructed. The prophetic arts assume that their statements will (actively) predict alternative possibilities that we must construct, but to the extent that they remain to be constructed, they have not been predicted. And to the extent that prediction actively influences that construction, it did not passively predict it.

The *paradox of prediction* makes two claims. The first is that, though we tend to think prediction makes a statement about the future, it's just a representation of our present understanding. Through *recognition* of emerging patterns in the present, prediction describes our understanding evolving. To the extent that it becomes fixed, it cannot evolve, and therefore will not predict.

A second aspect of the paradox: prediction is not necessarily passive. It may actively influence realization of the possibility it predicts. So there's a double reflection. Prediction both reflects and creates understanding. And to the extent that it "reflects" the future, it may also playa part in creating it. In the prophetic tradition, prediction may ambiguously suggest multiple possibilities, evolving with its interpretation. And it may actively influence the outcome of the events it predicts. Throughout this discussion we've implied a connection between the *paradox of prediction* and the process of invention. That connection is Thought (a process) and Understanding (its attempted result). Prediction, invention, and thought are all evolving constructs, chugging forward into the future, attempting on the way to create order with accident and inconsistency by recognizing *possible* emergent structures.

We've come full circle. We've recognized the blurry distinction between two concepts of prediction, the traditional scientific concept of passive prediction pointing to precise (or statistically probable) results, and the artistic concept of active prediction, both influenced by and influencing the outcome of events. Most contemporary scientists readily concede that their hypotheses can influence how they gathers their data and may affect their experimental results. So uncertainty is a governing principle in both domains. In quest of the future, science and the arts are more one culture than we might at first suppose.

As in the simplified microworld of chess, both analysis and synthesis (pattern recognition and creation) must collaborate to win the game, arts and sciences must collaborate to understand how the human mind constructs hypotheses or forms concepts.

Art and science have been contrasted: art associated with speculation, science with investigation. Nelson Goodman considered "art as inquiry," recognizing two complementary aspects of a single process — two complementary facets of our one culture. Many, notably Karl Popper, have recognized science as speculation. Prediction is possible if we are playing a game of Twenty Questions in which the Respondent knows the answer in advance. But in the uncertain game of possibility, the mind's most creative game, posing the questions demands both the scientist's systematic and the artist's exploratory approaches.

Scientist and artist are both like the camper searching for a box of matches with a flashlight in the dark, using what light they have to search for the light they do not yet have. Asking, "Where can it *possibly* be?" The answer cannot be predicted. It will emerge from the confused background of unrealized possibility. . . .

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ENDNOTES

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[1] Nelson Goodman. *Fact, Fiction, and Forecast*. (Cambridge, MA: Harvard University Press, 1983), p. 59.

[2] The term “selection criteria” refers to all of the components (e.g., rules, values, contextual conditions) that determine how a particular entity makes decisions. It does not presuppose consciousness. Thus the environmental context has selection criteria to select which organisms will survive. But the organism also has criteria by which it will individually fight for survival.

[3] Stephen Toulmin, *Foresight and Understanding: An Enquiry into the Aims of Science*. (New York: Harper and Row, 1963).

[4] See Ernst Mayr’s clarification of this important distinction in *The Growth of Biological Thought: Diversity, Evolution, and Inheritance*. (Cambridge, MA: Belknap Division of Harvard University Press, 1982), pp. 37, 57, 490, 863, and *Evolution and the Diversity of Life: Selected Essays*, (Cambridge, MA: Belknap, 1976), pp. 366–9.

[5] John Haugeland, ed. *Mind Design* (Cambridge, MA: M.I.T. Press, 1982), pp. 127–8.

[6] *Collected Papers of Charles Sanders Peirce* vol. 5, ed. Charles Hartshorne and Paul Weiss (Cambridge, MA: Harvard University Press, 1934), pp. 106-7 and *Philosophical Writings of Peirce*, ed. Justus Buchler (New York: Dover, 1955), pp. 151 – 2.

[7] Whether ambiguity lies in the prediction itself, or in our interpretation, its predictive impact is the same.

[8] The intention here is not to assert that all prophetic prediction takes an ambiguous, open-ended form, but rather that prophetic prediction had a range of possible forms, some of which were quite precise. For a study of the Delphic oracle’s precision, see Joseph E. Fontenrose, *The Delphic Oracle: Its Responses and Operations with a Catalogue of Responses* (Berkeley: University of California Press, 1978). This author suspects Themistocles of manufacturing the portent of the wooden wall to promote his own strategy. (pp. 124-8).

[9] Lewis Mumford, *Interpretation and Forecasts: 1922-1972*. (New York: Harcourt, Brace, Jovanovich, 1973), p. 476.

[10] Ray Kurzweil, *The Singularity is Near*. (New York: Viking Penguin, 2005).

[11] Jacques Monod, *Chance and Necessity: An Essay on the Natural Philosophy of Modern Biology*. trans. Austryn Wainhouse (New York: Alfred A. Knopf, 1971), p. 116.

[12] Jacques Hadamard, *The Psychology of Invention in the Mathematical Field* (Princeton, NJ: Princeton University Press, 1945).

[13] I am indebted to Arthur Loeb for this provocative question.

[14] Nelson Goodman puts this well: “A rule is amended if it yields an inference we are unwilling to accept; an inference is rejected if it violates a rule we are unwilling to amend.” See Nelson Goodman, *Fact, Fiction, and Forecast*, (Cambridge, MA: Harvard University Press, 1983), p. 64.

[15] I had already developed this argument when I discovered J .A. Wheeler's intriguing reference to the game to make a different but related point. One of the after-dinner party is sent out of the room, the others agree on a word, the one fated to be the questioner returns and starts his questions, posing one to each member of the group in turn. Then comes the plot. When you are out of the room, the group agrees not to agree on a word. Each successive question takes longer to answer, until finally you ask, “Is it a Cloud?” and someone says “Yes.” Wheeler in this thought experiment with the game is making a comment not only generally about indeterminacy but also specifically about the fact that, while observations in physics may be consistent, they are not predetermined; the observer (experimenter) is a participant in the emergence of the result. See John Archibald Wheeler, “Law Without Law,” in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek, Princeton Series in Physics (Princeton, NJ: Princeton University Press, 1983), pp. 200-1.

[16] Ray Kurzweil, *The Singularity is Near*. (New York: Viking Penguin, 2005).

[17] Slobodkin raises a related point: Evolution is like a game in which the only payoff is to stay in the game. So the strategy is neither to maximize efficiency, nor to achieve a particular reward [goal] but rather to keep playing the game — to persist by maintaining flexibility above all else. See L.B. Slobodkin, “The Strategy of Evolution,” *American Scientist* **52** (1964), pp. 342-57.

[18] See Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos: Man's New Dialogue With Nature* (New York: Bantam Books, 1984), p. 224.

[19] We should not here undervalue the “talent” of chess-playing programs. They do not simply use brute-force computation. Their decision-making procedure includes valuation functions about what moves are likely to contribute to center control, power balance, king safety, and so forth. They are able to consider not only the range of moves open to them in a given situation but also the likely future actions of their opponent.

[20] William G. Chase and Herbert A. Simon in "The Mind's Eye in Chess" wrote: "our earlier work, in conjunction with the pioneering work of de Groot, has led us to conclude that the most important processes underlying chess mastery are these immediate visual-perceptual processes, rather than the subsequent logical-deductive thinking processes. . . .De Groot found that Masters and weaker players have a great deal in common in the gross structure of their thought processes; he was unable to discover any quantitative differences that might underlie chess skill . . . . [However, one qualitative difference was that] Masters were able to reconstruct a chess position almost perfectly after viewing it for only about five seconds . . . . When the pieces were placed randomly on the board, recall was equally poor for Masters and weaker players. . . . It appears that the Master perceives familiar or meaningful constellations [i.e. patterns] of pieces." See William G. Chase, ed., *Visual Information Processing: Proceedings, Eighth Symposium*, Carnegie Mellon University, (New York: Academic Press, 1973), pp. 215–217.

[21] See Allen Newell and Herbert A. Simon, *Human Problem-Solving* (Englewood Cliffs, NJ: Prentice Hall Inc., 1972), and Marvin Minsky, *A Society of Mind*, unpublished draft, November 1985, p. 215.

[22] Wherefrom? and Whereto? were the questions psychologist Alfred Adler thought were implied in Leonardo da Vinci's free association Wordlists, a technique that scholars suspect da Vinci used to fuel his invention process. See references to "The Codex Trivulzianus" in Raymond Stites, *The Sublimations of Leonardo* (Washington, DC: The Smithsonian Institution Press, 1970), pp. 148-184.

[23] Michel Foucault, *The Archeology of Knowledge*, trans. A.M. Sheridan Smith (New York: Pantheon Books, 1972), p. 149.

[24] E.T. Owen, "Drama in Sophocles' Oedipus Tyrannus" in *Twentieth Century Interpretations of Oedipus Rex: A Collection of Critical Essays*, ed. Michael]. O'Brien (Englewood Cliffs, NJ: Prentice-Hall Inc., 1968), p. 40.

[25] Coherence-seeking may be linked to the phrase Jerome Bruner made famous, "going beyond the information given." He delineated several ways: using inference, using redundancy, recognizing sequential patterns, using formal methods and coding systems, transference. Psychologists Bruner and Potter conducted "Interference in Visual Recognition" studies in which subjects were presented blurred pictures of common objects that were gradually brought into focus. As might be expected, they found that the greater the initial blur of the image, the more delayed was its recognition and identification. (See Jerome S. Bruner, *Beyond the Information Given: Studies in the Psychology of Knowing*, ed. Jeremy M. Anglin (New York: W.W. Norton and Co., 1973), pp. 4, 220-1.)

[26] See *The Autobiography of Charles Darwin and Selected Letters*, ed. Francis Darwin (New York: Dover, 1958), pp. 42-3.

[27] *The 0rigin of Species*, sixth edition (1872), Chapter XV: "Recapitulation and conclusion," pp. 240-1. For reference to changes in the various editions of *The Origin of Species*, see *The Origin of Species: A Variorum Text*, ed. Morse Beckham (Philadelphia: University of Pennsylvania Press, 1959).

[28] See Etienne Gilson, *From Aristotle to Darwin and Back Again*, trans. John Lyon (Notre Dame, IN: University of Notre Dame Press, 1984), pp. 87.