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Varieties of Thinking

Essays from Harvard's Philosophy of Education Research Center

Edited with an Introduction by
V. A. Howard

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Contents

The design process

Donald A. Schon

Design, ambiguously signifying both process and product, is an extensible term that has been stretched, of late, to include not only the design of physical objects like buildings and tools, the traditional province of the so-called design professions, but organizations, plans, policies, strategies of action, behavioral worlds, and theoretical constructs—in short, the entire range of artifacts made by human beings.

In the very broadest sense, designing is the process by which things are made. In a sense only slightly less broad, designers make representations of things to be built. They shape materials to function in some context through a web of deliberate moves and discovered consequences, often unintended. Materials resist the imposition of form and it is a rare move that has only its intended consequences.

Designing, so considered, has a flavor of ancient Greece. Its study is a branch of poetics, derived from the Greek *poiein,* "to make." The casjuality of the design process suggests the interplay of Aristotle's materials, formal, efficient, and final causes—as we might expect, given Aristotle's understanding of caSjuality under the metaphor of design.

What would *not* be designing, on this view? Random or purposeless behavior; processes so proceduralized (like ringing up items on a cash register) that little or no room for decision remains; or the sort of action on materials (like the weathering of a rock) in which deliberate intervention plays a negligible part. We may design without knowing that we do so, but not without forming materials to function in some task environment.

In his well-known *The Sciences of the Artificial,* Herbert Simon has proposed a view of design broad enough to encompass the making of all varieties of human artifacts and a science of design that he characterizes as a "science of the artificial."[1] He regards this science as the primary basis for intellectual rigor in the professions, all professions, and he distinguishes it from the natural sciences. Whereas the latter are concerned, in his terms, with "how things are," the science of design is concerned with "how things ought to be, with devising artifacts to attain goals,"[2] and, so construed, makes up "the core of all professional activity ... the principal mark that distinguishes the professions from the sciences."'

In all these respects, Simon has done a great deal to lay the groundwork

for a much-needed epistemology of professional practice. The difficulty I have with his contribution is not the role he wants to create for a science of design but his approach to its definition. In this, moreover, Simon stands in a long tradition of theorists of design, decision-making, and problem-solving, a tradition that also includes, as I shall try to show, theories of biological, societal, economic, and policy change built on the metaphor of design. Adherents to this tradition have adopted certain fundamental strategies of analysis that seem to me to be radically incomplete. Through a critical analysis of Simon's theory, I want to explore how a more adequate theory of design might be developed.

In brief, Simon sees design as a problem-solving process. For him, design problems are instrumental problems in which one selects from available alternatives the best means for achieving some set of purposes, expressed in a "utility function." The designer transforms an existing state of affairs, a problem, into a preferred state, a solution. When his process is rational, it takes the form of a series of rule-governed decisions. Interestingly, natural science investigations and the discovery of mathematical proofs both qualify as design processes, in Simon's sense of the term, even though their subject matter has to do with the way things are rather than the way things ought to be.

The model of design as rational decision seems to me to be incomplete in three main respects, the first of which hinges on the idea of a design structure. A designer forms a representation of some initial design situation, framing a design problem that includes, when it is "well formed,"[4] elements from which to construct design options, a description of the situation in which options may be enacted as moves, and criteria sufficient to evaluate the effectiveness of proposed solutions. The design process is a series of transformations of such a representation according to rules that guide the sequencing and direction of design procedures. By design structure, I mean the designer's representation of a problem together with the rule-governed procedures that guide his transformations of it. In order for a design problem to be solvable, representation and procedures must be congenial to each other. In the case of Simon and others who hold the model of design as rational decision, the design structure is assumed to be given with the presented problem. For a rational decision process, in the sense required by the model, can occur only *within* such a structure. Hence the model does not explain how design structures are made and remade in the course of designing. In point of fact, well-formed problems and technical problem-solving tend to occur in actual designing only in later phases, after a basic design structure has stabilized.

Secondly, because of its division of designing into components of generation and selection, and because of its ways of conceiving of generation, the model of design as rational decision cannot account for important kinds of learning that occur within and across episodes of designing. In actual designing, designers often learn from earlier trials to reframe alternatives and even the problem itself. Moreover, each design project helps to prepare the designer for future projects. Designers "deuterolearn," in Gregory Bateson's phrase, to develop designs for designing.[5]

Finally, Simon, along with others of his general persuasion, tends to regard rational decision as a process that occurs within the mind of an individual. But actual designing is usually a social process, a dialogue among individuals in which different views of designing and different ways of framing design situations are pitted against each other. Design dialogues are dialectical unfoldings of conflicts among the views of design structure held by different parties to the dialogue. As design structures are made and remade in individual designing, so they are made and remade in design dialogues. Indeed, individual designing is often best understood as an introjection of design dialogue.

Design as rational decision

The model of design as rational decision depends on a strategy of analysis that divides designing into two main components, first the generation of alternatives (options for decision, or, as I shall call them, "design proposals", and second the selection of alternatives according to available decision rules. Rationality depends entirely on how selections are made. It is only a decision to select one option over others that *can* be rational or irrational, depending on its conformity or nonconformity to decision rules. Generating options is neither rational nor irrational but is best described as nonrational. In effect, the division of design processes into generation and selection is a strategy that separates out the one activity—decision making—that is presumed to be susceptible to rule-governed rationality.

A design process is considered rational, in the strongest and simplest case, if and only if its problem-solving steps are fully programmable under a set of designer rules. Simon illustrates such a case with his "diet problem":

> A list of foods is provided, the command variables being quantities of the various foods that are to be included in the diet. The environmental parameters are the prices and nutritional contents (calories, vitamins, minerals, and so on) of each of the foods. The utility function is cost (with a minus sign attached) of the diet, subject to the constraints, say, that it not contain more than 2000 calories per day, that it meet specified minimum needs for vitamins and minerals, and that rutabaga not be eaten more than once a week. The constraints may be viewed as characterizing the inner environment. The problem is to select the quantities of foods that will meet nutritional requirements and side conditions at the given price for the lowest cost. The diet problem is a simple example of a class of problems that are readily handled, even when the number of variables is exceedingly large, by the mathematical formalism known as linear programming. . . .[6]

In cases like this, the design problem is an optimization problem solvable by the use of techniques derived from utility theory, statistical decision theory, and linear programming.

In more complex examples, the design problem has a larger decision structure made up of a series of decision nodes, each of which represents a finite set of options for action or information gathering. Depending on the decision taken at a node, new outcomes arise which yield further decision nodes, and so on, until the criteria of problem solution have been met. Again, such a process is considered rational if it is fully programmable, but in a somewhat different sense. Rules given from the outset must specify either the decisions to be made at each node in the structure or the procedures for calculating the benefits and costs of all possible options associated with each possible set of outcomes.

Consider, for example, a patient-specific process of medical care where, in a presented clinical situation, the patient is found to have pulmonary edema. A basic treatment program specifies five responses: tourniquets, oxygen, aminophilin, digitalis, and diuretics. A fuller program specifies how the five responses relate to one another and to diagnostic conditions which could dictate exceptions to the simple program. For example, if digitalis has been given, or there is a prior history of digitalis, then diuretics are given and serum potassium is measured. If serum potassium is found to be low, potassium is given. If digitalis has not been given and there is no prior history of digitalis, then there need be no worry about potassium deficiency. The process can be represented by the following schema:

diuretics?

if no digitalis   *;/ digitalis*

yes (with impunity)   give diuretics; measure serum potassium

;/ low   *;/ normal or high*

give potassium   no potassium

Figure 7.1

In the diet problem, where the starting information is complete, rules specify procedures for selecting the best option. Where outcomes or information relevant to decisions are not fully known in advance, as in the clinical problem, additional information can be gathered by following rules specified in the decision structure. In both cases, a decision structure fully articulates procedures for information gathering and treatment. It specifies all possible interventions and their connections to outcomes, and all possible information-gathering steps and their connections to categories of resulting information. The clinical example illustrates how the design process may be rational, in the sense of fully programmable, even when the starting information is incomplete.

Generating possible options for decision

The model of design as rational decision assumes a fully articulated decision structure given with the design situation. But most actual design situations fall short of this ideal. For example, existing medical knowledge may not enable us to predict all relevant outcomes and options for information gathering or action; or the co-presence of multiple diseases may present decision problems for which we are unable to formulate an adequate set of decision rules. For investigators committed to the model of rational decision, it is tempting to peel back the layers of this onion: if certain features of a decision structure are missing in real-world design, it may be possible to separate them out, one by one, and specify programs to create them.

Simon follows such a strategy. Beginning with simple cases like the diet problem, he gradually moves toward the complexities of real-world design, considering, first, a problem in which the decision structure is completely given except for a full set of options. "We cannot, within practicable computational limits, generate all the admissible alternatives and compare their respective merits. Nor can we recognize the best alternative,even if we are fortunate enough to generate it early, until we have seen all of them."[8] Here, Simon makes explicit the analytic strategy by which he splits the design process into components of generation and selection. Once all the admissible alternatives have been generated, the problem can be solved by selecting ("recognizing") one alternative as the best according to rules based on principles of utility and statistical decision theory. But what about the generation of admissible alternatives? How are we to understand it, too, as a rule-governed, programmable process? To this question, the design literature offers two main answers: random generation of combinations of given elements, or systematic search. Both answers link theories of designing to theories of biological and social evolution that were originally developed, as I shall suggest, under the influence of a metaphor of design. Both answers seem to me to leave unexplained what is most in need of explanation.

Random generation

Randomness has often been used as an approximate substitute for creativity in theories of problem solving, especially in the heuristic programming favored by Artificial Intelligence. But the idea is of much older provenance. Theories of biological, social, and economic evolution, of policy formation, of the psychology of creativity, and of organizational innovation have all relied, at various times, on a model according to which randomly generated design "proposals" are subsequently "disposed of according to various criteria of selection. The beauty of this model is that one need not claim to know much about the generative process; ignorance is acceptable. Its cost is that one cannot identify particular proposals in advance but only the elements from which they will be constructed.

Here, the designer is assumed to have access to elements of design given with the design problem. Design options are combinations of elements, randomly generated (for example, by using a table of random numbers). Once generated, they are screened on the basis of criteria that are also presumed to be given with the design problem.

In some cases, theorists do not explicitly introduce the idea of randomness but treat the generation of combinations of elements as a blind, essentially mysterious process *as though* it were random.

Darwin's theory of the evolution of biological species asserts that random genetic variations yield a continuing supply of biological possibilities which are selected or rejected on the criteria of their fit with a changing environment. The evolving design of biological species results from many cumulative increments of generation and selection, "proposal" and "disposal." Although the great majority of proposals generated are inappropriate under given criteria of selection, some few turn out to be adaptive; their incremental incorporation into the genetic store of a species accounts for its evolution.

Darwin first applies this formulation to man's breeding of preferred varieties of plants and animals:

> ... A high degree of variability is obviously favorable, as freely giving the materials of selection to work on; not that mere individual differences are not amply sufficient, with extreme care, to allow of the accumulation of a large amount of modification ,in almost any desired direction. But as variations manifestly useful or pleasing to man appear only occasionally, the change of their appearance will be much increased by a large number of individuals being kept. Hence the number is of the highest importance for success. . . . But probably the most important element is that the animal or plant should be so highly valued by man, that the closest attention is paid to even the slightest deviation in its qualities or structure.[9]

He went on to explain the mechanism of biological evolution in terms of the metaphor of "natural selection":

> If then, animals and plants do vary, let it be ever so slightly or slowly, why should not variations or individual differences which are in any way beneficial, be preserved and accumulated through natural selection, or by survival of the fittest?[10]

Social Drawinists applied a version of Darwin's theory to explain the evolution of societies. In *Social Change,* for example, William Ogburn spoke of the "selective cumulation" of customs:

> The material cultures possessed by a people in a particular location will, over a long period of time, show a large proportion actually lost. This would not be true to so great an extent for the world as a whole, though. However, it is certainly more accurate to refer to this particular cultural process as selectively cumulative; and by selective accumulation is meant the fact that new forms of material culture are added and some old ones discarded, there having been a selection. The additions have exceeded the discards, so that the stream of material culture of a particular people has widened with time."

And economists, from Adam Smith onward, have relied on a model of the free market economy according to which the hidden hand of the market selects among products and production methods generated by firms, in ways unspecified by the theory, in order to secure the firm's competitive advantage—a process whose collective, cumulative result is economic progress.[12]

Christopher Alexander adopts a variant of this model in his description of processes of cultural design, by which a culture's artifacts reach what Alexander calls "an equilibrium of well-fitting forms":

> The basic principle of adaptation depends on the simple fact that the process toward equilibrium is irreversible. Misfit provides an incentive to change. Good fit provides none. In theory, the process is eventually bound to reach the equilibrium of well-fitting forms.[1'1]

By way of illustration, Alexander offers his well-known example of Slovakian peasant shawls:

> The Slovakian peasants used to be famous for the shawls they made. These shawls were wonderfully colored and patterned, woven of yarns which had been dipped in homemade dyes. Early in the twentieth century aniline dyes were made available to them. And at once the glory of the shawls was spoiled; they were now no longer delicate and subtle, but crude. This change cannot have come about because the new dyes were somehow inferior. They were as brilliant and the variety of colors was much greater than before. Yet somehow the new shawls turned out vulgar and uninteresting.

> Now, if as it is so pleasant to suppose, the shawlmakers had had some innate artistry, had been so gifted that they were simply "able" to make beautiful shawls, it would have been almost impossible to explain their later clumsiness. But if we look at the situation differently, it is very easy to explain. The shawlmakers were simply able, as many of us are, to recognize *bad* shawls, their own mistakes.
>
> Over the generations, the shawls had doubtless often been made extremely bad. But whenever a bad one was made it was recognized as such, and therefore not repeated. And though nothing is to say that the change made would be for the better, it would still be a change. When the results from such changes were still bad, further changes would be made. The changes would go on until the shawls were good. And only at this point would the incentive to go on changing the patterns disappear.
>
> So we do not need to pretend that these craftsmen had special ability. They made beautiful shawls by standing in a long tradition and by making minor changes whenever something seemed to need improvement. But once presented with more complicated choices, their apparent mastery and judgment disappeared. Faced with the complex unfamiliar task of actually inventing forms from scratch, they were unsuccessful.[1'1]

Alexander does not use.the word 'random.' He suggests something like it, however, when he speaks of generating changes in shawls, without saying how they are generated, and observes that changes are as likely to be for the bad as for the good. In order to account for an eventual equilibrium of well-fitting forms, he need postulate only the shawlmakers' ability to recognize needs for "improvement," generate new combinations from variables of color and pattern, distinguish good from bad changes, and store in cultural traditions the know-how to produce shawls that retain good changes.

Like Alexander, proponents of an incrementalist approach to planning and policy making—Charles Lindblom, for example[15]—take minor changes as the units of design. On this view, planners and policy makers always begin with an existing design; their limited knowledge and constrained situations prevent them from designing new forms from scratch. They initiate minor changes out of a confused sense that something needs improvement. According to some versions of incrementalism, policy changes, *ex ante,* are just as likely to be bad as good, but the good changes are more likely to be retained. The process of selective retention is sometimes attributed to planners (who, like the shawlmakers, are assumed to recognize bad changes when they see them) and sometimes to a kind of natural selection operating in the policy environment, leading in either case to a gradual, cumulative progress in policies and plans.

I have noted elsewhere that an analogous process was common to research and development practice in business firms during the late 1950s and early 1960s.

> Those to whom the entrepreneurial task had been delegated confronted the new problem of innovation from within the corporation. They had no authority

> to take leaps of decision on insufficient information which are essential to innovation. Instead, they could only propose upward to the boss, who disposed . . . Those below proposed; those above disposed.
> The process of innovation still had in it all the randomness and uncertainty . . . [the subordinate] was continually floating balloons to the top of the company. He would find the balloons, inflate them, let them go, and wait to see whether they were shot down. Usually . . . they were. He would then have to infer, from inspection of balloons shot down and those allowed to go up unimpeded, just what would make a new development "go" in his company. . . ."[16]

Here we also find a random, or at any rate unspecified, process for generating many proposals, together with a tightly controlled method (the boss's judgment) for selecting a few of them, on the basis of criteria not necessarily fully specified in advance. In the '50s, managers not only used the propose/dispose system but touted it as a superior means of achieving product innovation.

When the model of random generation/programmed selection is carried to the workings of an individual's mind, we have theories of creative problem-solving like that of Henri Poincafe, who proposed a stage theory of mathematical invention: first, conscious work on a problem; then a period in which ideas are incubated; sudden illumination; and finally a new round of conscious work that confirms and develops the original insight.[17] Poincafe is particularly concerned to explore how unconscious work can produce illumination:

> It is certain that the combinations which present themselves to the mind in a sort of sudden illumination, after unconscious working somewhat prolonged, are generally useful and fertile combinations. ... all the combinations would be formed in consequence of the automatism of the subliminal self; but only the interesting ones would break into the domain of consciousness.
> . . . Among the great numbers of combinations blindly formed by the subliminal self, almost all are without interest. . . .[18]

Triggered by conscious work on a problem, conceptual elements are blindly combined in a "subliminal" process like the swirl of molecules in a gas (to use Poincafe's analogy). Only "useful and fertile" combinations rise to consciousness, the others being preconsciously screened out on the basis of aesthetic criteria: ". . . only certain ones are harmonious . . . and capable of touching this special sensibility . . . which, once aroused, will. . . give them occasion to become conscious."[19] Illumination occurs, then, when random combinations of ideas, generated unconsciously through processes set in motion by conscious work, are subjected to conscious screening. Only the "fertile" combinations—happily, the aesthetically pleasing ones—are presented to consciousness for further employment in conscious problem-solving.

All theories of random generation/programmed selection show striking similarities, as well as instructive differences. First, they are all, on our criteria, descriptions of designing. Only Alexander, it is true, speaks explicitly of design; but all of them—theorists of biological, social, and economic evolution, organizational innovation, and creative problem-solving—present descriptions of processes in which actual situations are changed into more desirable ones as initially given materials are formed, through the generation and selection of alternatives, into artifacts suited to their environments.

It is a moot point whether, in all these cases, designing is seen as a deliberate, purposeful activity. Interestingly, however, even theorists of social and economic evolution are drawn to the metaphor of an intentional, supra-individual designer: "society" selectively accumulates, the "hidden hand" of the marketplace chooses. And—as we have already noted—Darwin's theory of natural selection owes a great deal to his observations of breeding practices in common use among the English farmers of his time.

All of these writers regard many iterations of the generation/selection process as conducive to progress of a sort, though the meaning of progress shifts with the domain under consideration.

All of them share a model under which new possibilities for decision, generated out of known elements through an unknown or unknowable process, are subjected to selective screening on the basis of some established procedure. For all of them, that procedure has to do, in one way or another, with the detection of design proposals fit or misfit in relation to some environment. But the writers have different ideas about the nature of environment and of the processes by which fit or misfit is detected. Poincare, for example, posits a preconscious screen that operates on the basis of aesthetic criteria. For Darwin, fit or misfit depends on whether or not a variation or individual difference enhances an organism's chances of survival in its biological environment—a criterion that depends, in turn, on the particular characteristics of the organism, its changing environment, and the organism/environment transaction. In theories of the evolution of societies, markets, cultures, or policies, fit or misfit is determined by certain individual and collective judgments or preferences. The theories need not (and usually do not) describe the bases on which such judgments or preferences are exercised. The problem is shifted, as it were, to the individuals in question.

The existence of such a diverse group of adherents, operating in such varied domains, suggests how wide-ranging has been the influence of the model of random generation/programmed selection. Clearly, it is very attractive. Nevertheless it presents serious difficulties, especially when it is taken not only as an after-the-fact account of design processes but as a normative, prospective model for designing. All of these difficulties hinge on discrepancies between certain of the model's assumptions and the characteristics of actual design processes.

In brief, the model assumes that design proposals are simple or merely additive, independent of one another, and incremental in their impact on design structures. But in actual designing, design proposals are often complex, interdependent among one another, and significant in their impact on design structures. Moreover, the model assumes that design structures are given with the design situation, whereas in actual design processes, structures are frequently made and remade in the course of designing. Each of these arguments requires elaboration.

First, let us consider the question of simplicity and complexity. In Simon's diet problem, foods are "simples" (considered, for the sake of the problem, as undecomposable units of design) and "diets" are complex in the sense that they are combinations of quantities of foods. Their complexity, however, is of a combinatorial or merely additive kind. When a particular food is added or subtracted, the diet is assumed to be changed only to the extent of that addition or subtraction. This is in contrast to the kind of complexity I will call *figural,* where addition or subtraction of one element changes the functional meanings of other elements with the result that the proposal must be considered different *as a whole.* Examples of figural complexity are to be found in the familiar drawings of the Gestalt psychologists; in music or painting, where the addition of a single note to a melody or a single patch of color to a composition can change the meaning of the design; or in systems—machines, buildings, computer programs, or human organizations, for example—where a change in the position, features, or functions of one element can produce significant changes in other elements and in the system as a whole.

The question of simplicity and complexity is closely linked to that of independence and interdependence. Two design proposals, or two elements of a proposal, are independent when one element's fit or misfit in a design structure does not depend on the presence or absence of the other. They are interdependent when the fit or misfit of their conjunction differs from their fit or misfit when they are taken alone. In an additively complex proposal, elements are independent of one another; in a figurally complex proposal, they are interdependent.

The model of random generation/programmed selection depends on the assumption that design proposals are simple, or merely additive, and independent of one another. Otherwise, the idea of random generation does not make sense. For if the elements of design proposals are interdependent, then they are objects of design in their own right. If such proposals are explainable by random generation, then why not the design structure as a whole? The design process would then be conceived as a series of mysterious, essentially unknowable guesses at complete solutions—a black box that would leave unexplained what is most in need of explanation. But in much actual designing, proposals are figurally complex. To

return to the clinical example given earlier, digitalis, diuretics, and potassium are functionally interconnected: diuretics reduce body fluids so that the heart has less work to do, and digitalis stimulates the heart muscle, but at the risk of reducing serum potassium below normal levels. Hence the competent clinician considers diuretics, digitalis, and potassium as interdependent elements of a figurally complex proposal for treatment, and an adequate theory of actual designing must explain how such proposals are constructed.

A similar argument can be made in the case of biological evolution. The familiar example of the giraffe's long neck is misleading. For the long neck is part of a giraffe system which includes a long and prehensile tongue capable of grasping food at the tops of trees, long legs which add to height and are designed for flight, and a digestive system attuned to the kinds of food best found with the help of the long neck. It is unlikely that one of these features would be adaptive in the absence of the others and therefore unlikely that they would emerge in their present systematic relations to one another through a process in which they were generated and selected in complete independence of one another. It would be more plausible to say that "design options" consist of alternative states of the total system.

Of course, one might posit a giraffe system consisting of all the elements and relations described above *except* for the long neck. Then a random genetic variation that contributed to a longer neck might be adaptive. But this sort of posit raises the question of the origins of basic design structures, to which we will return below.

When do conditions of independence and simplicity, or additive complexity, hold true? They hold for problems artificially constructed to *make* them hold. The diet problem is such a case, though even here it is interesting to note in recent nutrition science indications that foods contained in a diet may affect one another's nutritional value. These conditions also hold for certain classes of operations research problems where, as Simon points out, a large number of independent variables can be handled by the mathematical formalism of linear programming.

A further class of examples where these conditions may hold consists in processes where structures are built up from scratch through the combination of regular geometric solids. Certain biological forms, like honeycombs and wasps' nests, may fall into this category, along with self-organizing systems like crystal growths and structures formed by the close packing of certain regular solids. In these instances, the design structure consists in an array of more or less identical objects, each of which has a great deal of design built into it. Here, there are very few ways in which elements can combine and the resulting combinations set precise requirements for the addition of the next element.

In actual human designing, these conditions tend to be met only in later phases of a design process when the central features of a design structure are presumed to be set and stabilized, and only peripheral details remain in question. One might imagine, for instance, that the formula for a fabric softener has been fully defined and there remains only the question of its perfume. Or one might consider a machine that has been fully designed except for the color and texture of its housing. Even in such cases as these, however, the addition of final touches sometimes affects central features of a design structure in unanticipated ways, sending designers back to the drawing board.

If the model of random generation/programmed selection is limited in its applications to cases like the ones described above, then it is limited indeed! It holds only for a narrow range of artificially constructed problems, perhaps for certain examples of self-organizing systems, and for the later phases of certain other design processes. The attempt to apply the model more generally rests on the mistaken notion that the initial development of a design structure follows a pattern that actually holds only for the structure's final elaboration. Moreover, when the model is made into a normative prescription for effective designing, it becomes a recipe for conservatism. Designing, the theory then states, *should* proceed through the random generation and programmed selection of minor changes.

Just as the model of random generation/programmed selection cannot explain the figural complexity of design proposals, so it cannot explain the figural complexity of design structures. But in actual designing, figurally complex design structures come into being not only at the inception of the design process but, characteristically, over and over again throughout the process.

The making and remaking of figurally complex entities—proposals and structures—occur in several different ways, all of which derive from the designer's experience in the process, and are understandable as kinds of learning. What must be explained, then, are the kinds of learning on which skillful designing depends.

Let us consider this issue in the light of Alexander's shawlmakers. Figure 7.2 is a schema of the design process Alexander describes:

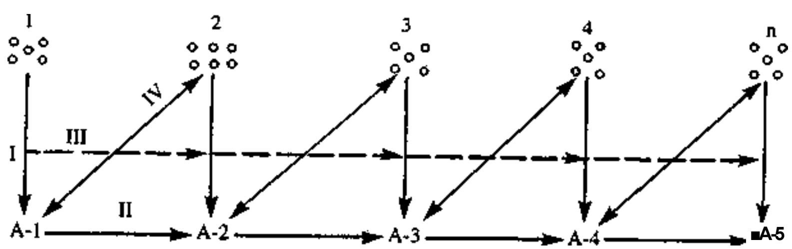

Figure 7.2

In this schema, the Arabic numerals refer to trials in which a designer introduces a particular change in pattern and/or color. Each trial is presented as a selection of one design option from a range of possible options (though, of course, no such choice is necessary; the shawlmaker might simply make what seems to be the 'right' move, without any conscious consideration of options), with the selected option indicated by a darkened circle.

When a designer introduces a change in color or pattern, the shawl changes. It is different just to the extent that it now incorporates the change which the designer has introduced—a difference, I claim, that often involves a change in figural, not only additive, complexity. The shawl is changed not only by the addition or subtraction of one element of color or pattern but changed as a whole figure, just as a melody can be changed as a whole by a shift in the duration or pitch of one or more of its elements. A-1 through A-n signify the changed states of a shawl consequent on each of the designer's moves. I label these symbols "representations" in order to be consistent with my view of designing as a process in which the designer's *representation* of a design situation undergoes a series of transformations. One might think of A-1 . . . A-n as standing for the designer's changing internal representation of the shawl, or one might think of the actual shawl as a representation of itself.

A-1 . . . A-n might also stand for different shawls, made at successive times, where the making of A-2 is informed by the designer's appreciation of A-1, and so on. Alexander's description of successive trials, and successive perceptions of fit or misfit, seems to lend itself to either of these interpretations.

The arrows in Figure 2 stand for different processes of enactment, change, or learning. The arrows labelled "I" stand for the enactment of a design option, the move by which the designer introduces the change she has selected. The arrows labelled "II" stand for processes of transformation: the process for example, by which A-1 becomes A-2. The arrows labelled "III" and "IV" stand for paths of learning, their different starting- and end-points signifying different ideas of the learning process, an issue, to which I shall return shortly.

With each new trial, 1 through n, the designer selects a new element of color or pattern, and makes her judgment—according to Alexander's description—on the basis of its fit with the existing state of the shawl. The designer selects a change that fits that state and rejects the ones she perceives as misfits. But each such judgment differs from the previous one, not only because new design options are now in question but because the shawl is now perceived (represented) as a new entity. Judging whether a given design proposal fits A-2 is not the same as judging whether it fits A-1. In my terms, the criteria of fit have changed because the design structure has changed. Now Alexander attributes to the Slovakian peasant shawlmakers a capacity to make just such shifting judgments of fit and misfit, but it is not part of his intention to say how they do it. They *recognize* fit or misfit under continually changing conditions (so long as dyes, yarns and patterns sufficiently resemble the ones they are used to). If, on the other hand, one wished to give a formal description of the criteria under which successive judgments of fit or misfit were made—in order to construct a computer program to design shawls, for example—then it would be necessary to formulate rules and/or procedures by which to determine, for each state of the shawl, which of a given range of design options fit that state. The strategy of such a description, or program, would consist either in specifying from the outset all relevant criteria of fit for all possible shawl-states, or in devising rules and procedures by which, given any particular state of the shawl and any set of design proposals, fit or misfit could be determined. This level of cognitive complexity must be incorporated in the process I have called "programmed selection," once we recognize that design proposals interact with design structures in a figurally complex way.

In actual designing, successive trials are not independent of one another, as in the familiar idea of "blind" trial and error where one keeps on trying things *(anything,* in the end-case of a blind process) until something "works." The designer's choice of a new color or pattern is likely to be influenced by previous judgments of fit or misfit, that is, by learning from previous trials, and paths of influence may differ depending one one's view of the actual learning process.

In what is perhaps the simplest case of learning, the shawlmaker might judge among options at 2, as I have described above, on the basis of fit or misfit with the new state of the shawl that had resulted from trial 1 (as indicated by the arrows labelled "IV"). In this case, one might conceive of the shawl itself as a repository of learning derived from previous trials; each new state of the shawl, as perceived by the shawlmaker, provides a new context in which the next judgment will be made. In a second case, one might conceive of the shawlmaker as making a judgment at the moment of any given trial on the basis of her appreciation of the previous trial (as indicated by the arrows labelled "III")—or on the basis of *all* previous trials. In each such instance, she would be seeing the presented situation as a version of the preceding—saying to herself, for example (if one imagines spelling out in discursive reasoning the judgment she probably makes immediately and tacitly), "Just as a contrasting color worked there, so it may work here," or, "Just as I intensified that pattern at the corner with a gold thread, so I should match it with a gold thread here."

All such learning depends on the designer's perception of the earlier trial(s) and the present one, and on her appreciation of the significance of the earlier trial(s)—their implications, potentials, constraints—for the present one. These relationships also involve figural complexity. One might imagine the designer entertaining, in her mind's eye, the juxtaposition of an earlier trial and a possible future one, judging some of these conjunctions as "fits" and others as "misfits."

In short, actual design proposals are generated *and* selected through processes of learning that involve appreciations of figural complexity. When they are enacted, they change design structures in ways that set new conditions for the judgment of fit or misfit. These observations hold, I suggest, not only for examples like shawlmaking but for designing the full range of human artifacts. And they are not described or explained by the model of random generation/programmed selection.[20]

Systematic search

An alternative approach to the generation of design options, or proposals, is that they are the results of a designer's systematic search. With this explanation, the underlying metaphor shifts from the random or blind combination of design elements, given with the problem, to the intelligent exploration of a terrain—or, as Simon calls it, a "problem space."

During World War II, the U. S. Navy's Weapons Evaluations Group addressed the problem of submarine search, which was one of the first to be approached through the new techniques of applied mathematics. It became a formative problem for the developing science of operations research and gave rise to a branch of applied mathematics called search theory. Given the metaphor of search (as in "searching for answers"), already built into ordinary language, it is no wonder that efforts should then have been made to extend search theory broadly to processes of problem solving and design.

Simon presents the view as follows:

> When we take up the case where the design alternatives are not given in any constructive sense but must be synthesized, we must ask once more whether any new forms of reasoning are involved in the synthesis, or whether again the standard logic of declarative statements is all we need . . . once we have found a candidate we can ask: Does this alternative satisfy all the design criteria? Clearly this is also a factual question and raises no new issues of logic. But how about the process of *searching* for candidates? What kind of logic is needed for search? ...
>
> GPS [a problem-solving program developed by Simon and his colleague, Allan Newall] is a system that searches selectively through a (possibly large) environment in order to discover and assemble sequences of actions that will lead it from a given situation to a desired situation. . . .
>
> To represent the relations between the afferent and the efferent worlds, we conceive GPS as moving through a large maze. The nodes of the maze represent situations, described afferently: the paths joining one node to another

> are the actions described as motor sequences, that will transform one situation into another. At any given moment, GPS is always faced with the single question: "What action shall I try next?" . . . It is characteristic of the search for alternatives that the solution, the complete action that constitutes the final design, is built from a sequence of component actions. The enormous size of the space of alternatives arises out of the innumerable ways in which the component actions, which need not be very numerous, can be combined into sequence.[21]

On this view, the paradigmatic process of problem-solving becomes search for the best path through a maze. The maze is a network of paths of action, similar to the network of a decision structure, within which each path leads to a particular modification of the original situation. The heuristics of search for the best path through a maze become broadly accessible for solving problems, including those not ordinarily seen as problems of search, just as in the previous case all problem-solving was seen in terms of the selection of randomly combined elements. In both cases, the effort is to subsume all problem-solving under the schema of a process we know how to program. Simon adds, however, that

> . . . problem solving systems and design procedures in the real world do not merely *assemble* problem solutions from components, but must *search* for appropriate assemblies. In carrying out such a search, it is often efficient to divide one's eggs among a number of baskets—that is, not to follow out one line until it succeeds completely or fails definitely, but to begin to explore several tentative paths, continuing to pursue a few that look most promising at a given moment. If one of the active paths begins to look less promising, it may be replaced by another that had previously been assigned a lower priority.[22]

Search for solution proceeds *via* search for the most promising paths to solution, which one must be able to compare and evaluate for relative promise early in the design process. Rational design depends not only on applying utility and statistical decision theories to alternatives within a fully articulated decision structure, be on the designer's ability to carry out an intelligent search for paths to solution.

Simon devotes several sections of his book to this topic. He begins by recognizing the interaction of component paths: "Actions have side consequences (may create new differences) and sometimes can only be taken when certain side conditions are satisfied (call for the removal of other differences before they become applicable)."[23]

Hence, one cannot usually construct an effective path to solution by adding the component paths that remove a unit difference between problem and solution states. It is necessary to "search for assemblies"

which are "appropriate" in the sense of taking interaction of components into account.

Simon goes on to consider how designers should calculate the "costs" in.expenditure of design resources and "benefits," in promise of solution, that may be associated with an assembly of paths. He presents Marvin Mannheim's proposal to organize problem space into a hierarchy of global and local paths to solution, which permits a progressive global-to-local search.[24] He makes reference to other search programs which assign values to assemblies, "as processes for gathering information about problem structure that will ultimately be valuable in discovering a problem solution."[25] And he considers programs which begin with the functional decomposition of a problem, such as building a house, in order to permit application of "generator/test" cycles to each of the functional components of the problem. He admits, however, that, "A theory of design will include principles—most of which do not yet exist—for deciding such questions of precedence and sequence in the design process."[26]

So long as design theorists explain the generation of design options in terms of the systematic search of a problem space, they must assume— whatever new principles they may discover—that a great deal of structure is given with the design problem. Consider Simon's image of moving through a large mass.

An actual maze has a structure. At the very least, it has an entrance, a way out, and a network of paths connecting entrance to exit. Some paths are blind alleys; others open onto other paths. Combinations of paths may also lead to dead ends, or to other assemblies, and at least one route through combinations of paths leads to the exit—so long as the problem represented by the maze is soluble.

When systematic search of a problem space is conceived in terms of the metaphor of running a maze, design options are taken to be paths or combinations of paths. They exist in the maze, and one must discover them in order to try them. But trying them does not change them. The maze runner is seen as learning *about* paths and interconnections of paths that are there to be discovered. As he tries one path after another, the maze runner may learn. His success in solving the problem depends on his learning to discover strategies for selecting and sequencing paths to be run and on his complementary discovery of the maze's structure, the spatial configuration in which paths are related to entrance, to one another, and to exit.

To the extent that actual design situations have this mazelike structure and lend themselves to these sorts of discovery, maze running may be a fruitful metaphor for generating and selecting design options. But his depends on a certain *objectivism.* For any particular maze, the same configurations of paths must dependably present themselves to anyone who chooses the same initial path. Just as the model of random generation assumes that design elements are given with the problem and treats combinations of these elements as objectively discoverable, so the model of systematic search assumes that paths are given with the problem and their subassemblies are objectively discoverable. The designer's discretionary freedom to invent and choose is limited to *strategies* of search whose consequences (discovery or non-discovery of subassemblies) are, again, implicitly given with the structure of the problem.

What sorts of problems fit these conditions? In the first instance, artificially constructed problems, like the well-known "Towers of Hanoi," and problems that lend themselves to the use of operations research techniques. Beyond these sorts of examples, any problem may be *made* to fit these conditions by giving it a well-articulated structure, so long as the problem solver sticks to that structure.

But the model of systematic search explains neither the development of design structures nor the development of figurally complex options in which the meaning of a given path changes significantly when it moves from one context to another. In this model, there is room for the designer's learning, but only for learning about subassemblies whose elements are presumed to be given with the problem and remain constant throughout the process. Hence, it does not account for kinds of learning—like the shawlmakers' learning, described above—where, in the process of designing, the designer comes to see the situation, design trials, and criteria of fit in new ways. Systematic search does not account for cases in which running the maze changes the maze.

Both models of generation, random combination and systematic search, lead to a dilemma. One must either forego the model's application to many of the most interesting cases of design, or assume as given a pre-existing structure that the model leaves unexplained. In this respect, Alexander's view of cultural design is like Simon's General Problem Solver. Both are partial theories of the design process, leaving unexplained how in the course of designing basic design structures and figurally complex design options are formed and transformed.

It is useful, of course, to explain what it means to be rational or effective *within* a design structure. One might even claim that we do not ordinarily have to create design structures from scratch, but only to modify existing ones. But for many kinds of problems—of organizational, policy, and program design, as well as design of the physical environment—even the modification of an existing design structure requires transformations that lie beyond the models described by Alexander or Simon.

It is for these processes of formation and transformation that I reserve the term "synthesis." And for synthesis, in this sense, there exists no adequate theory. There is not even a serious contender.

This I take to justify the very exploratory comments that follow. They are intended to suggest some of the things a theory of synthesis should

be about, and some of the directions it might take. I shall draw my examples from social policy and service delivery systems, a field I know something about through my work with Martin Rein. However, other fields of design might equally well have been chosen.

Synthesis of design structures: the case of service delivery systems

Service delivery systems include services related to housing, criminal justice, health, welfare, education, and manpower—indeed, any service provided to a broad clientele, distributed through interconnected networks of agencies, under a system of regulations and policies, drawing on established funding sources.

It is difficult to make sense of data about a service delivery system in such a way as to yield coherent and persuasive recommendations for policy. Often, studies of service delivery systems result in assemblies of facts, clustered in one part of a report, and a set of unrelated recommendations in another. Prevailing notions of social science methodology play a particularly villainous role. Students, in particular, often feel that it is incumbent on them to generate "hypotheses" (for example, "Decision processes work more slowly in large organizations"), which they conceive as projected correlations of variables. They are puzzled when such hypotheses turn out to be unconfirmable or, if they are confirmed, turn out to lead nowhere.

Martin Rein and I have found it useful to ask our students, once they have immersed themselves in data about a particular system, to tell a diagnostic/prescriptive story about the system, one that indicates what is wrong with it and how it can be set right.[27]

Two such stories, in abbreviated form, are as follows:

> There is a group of people in need of service. The services they need are varied and complex, consisting of many different kinds of specialized treatment. Their delivery must be differentiated according to the needs of different individuals, or the same individual over time, and they must be administered in a coordinated way so that services are linked to one another and easily accessible to clients.
>
> In the past, these services were integrated and accessible. Now, however, they are fragmented; each type of service is offered in a different place by a different provider, with no coordinated interconnection among them.
>
> This may have happened for any one of several reasons. Perhaps functions have become more specialized, as service providers have professionalized. Perhaps the clients themselves—families, or neighborhoods—have broken apart.
>
> Whatever the causes of fragmentation may be, clients are now unable to get easy access to the services they need, nor are services delivered in a

coordinated, continuous way. As a consequence, clients suffer. They do not get what they need in the way they need it.

The story may be told about social welfare services, in which case it refers to the decline of urban neighborhoods, the abandonment of neighborhood settlement houses and the subsequent establishment of many specialized social welfare agencies to which clients no longer have unified access. Or it may be a story about health services, and then it refers to the decline of the old-style family doctor, and the rise of medical specialists no one of whom really knows much about the patient.

> Some people need a kind of service they can now get only if they remain in institutions specially designed for its provision. But institutions are custodial; they restrict residents' freedom of action and isolate them from their natural home communities.
>
> Through prolonged residence in an institution, people become institutionalized. They adapt so well to the special requirements an artificial institutorial life that they become ill-adapted to life in the real world.

This story may be told about mental hospitals, prisons, old age homes, or centers for delinquent youths.

Stories such as these are archetypal. The crop up in discussions in many different fields of social policy. They underlie not only the responses of students but the work of researchers in the field.

They are also useful. They enable the storyteller to select for attention a very few features of the material which, however, fit into a pattern that is both descriptive and normative, diagnostic and prescriptive. The synthesis of "facts" about the system is also a way of pointing toward recommendations for policy.

In the first case, the story of fragmentation leads to a prescription of coordination. If services were once whole and now are fragmented, then the problem is how best to make them whole again.

In the second case, the diagnosis of institutionalization leads to a prescription for community care. If individuals are damaged through their segregation in institutions and their isolation from communities, then the problem is how best to reintegrate them into communities.

In each case, the story contains a basis for moving from diagnosis to prescription, from facts to policies, a movement that Rein and I have called the "normative leap."

In the first story, the basis of the normative leap is the notion of fragmentation. Services are seen as having been whole, as fragmented now, and as needing to be made whole again. But services do not literally fragment like a physical object that can be broken into parts. We are dealing here, then, with a metaphor—the metaphor of something like a bowl that can be broken and reassembled. It is a metaphor, moreover,

which embodies a normative idea. A bowl is *better* whole than fragmented and, other things being equal, if the bowl has been broken, it is *right* for it to be made whole again. When this idea, drawn from the realm of bowls and vases, is transposed to services, it yields the notion that services are better off integrated than fragmented, and that it is right to reintegrate services that have been fragmented. That the plausibility of this recommendation derives from the metaphor of fragmentation can be seen by substituting another metaphor for it. A story might have been built around the idea of services growing from an early stage of mutual dependence to a later stage of maturity in which they become independent. Would it be obvious, then, to say that it is better for them to be "whole," where wholeness signifies mutual dependency?

In the second story, the metaphor is that of a building like a prison which segregates persons and isolates them from a home community outside. Given the familiar ideas that surround institutional buildings and home communities, it is plausible—even obvious—that people are better off in their communities than in isolated buildings. But what if the metaphor were that of protection? Then it might seem obvious that people are better off in institutions (like the early "reform schools" in Massachusetts) where they can be protected from the dangers and distractions of, for example, a dirty, crime-ridden urban neighborhood. Or what if the institution itself were seen as housing a community? Then it might seem obvious that people are better off as members of an institutional community rather than as residents of a home environment where they suffer from isolation or anomie.

Generative metaphor

The two stories facilitate the normative leap because they are built on generative metaphors, families of familiar ideas carried over *(metapherein,* in the Greek) to a new situation for which they serve as projective models.[28] The familiar ideas contain normative evaluations; they describe things in ways that reflect what Geoffrey Vickers has called an "appreciative system."[29] For example, as I have mentioned above, objects like vases and bowls are better whole than broken, at least under ordinary conditions. Hence, when familiar ideas are carried over to a new situation, the new situation comes to be evaluated as we evaluate the familiar one. The metaphor generates a description of the unfamiliar situation in which the normative leap is already made; facts carry normative weight. Once we are able to see a service system as fragmented, we find it obvious that the system needs to be made whole. Once we see an institution as an artificial environment that confines people and isolates them from their natural communities, we find it obvious that people should be freed up to return to their natural settings.

Generative metaphor produces a selective representation of an unfamiliar situation that sets values for the system's transformation. It frames the problem of the problematic situation and thereby sets directions in which solutions lie and provides a schema for exploring them.

Metaphors are simple notions, easily held in the mind, but they stand for complex families of ideas. The creation of a design structure requires precisely such a hybrid of simplicity and complexity. The metaphor of fragmentation, for example, refers to a phenomenon about which we already know a great deal. Hence, the simple metaphor of fragmentation is able to function as a formula that compresses a great deal of information. Everything we know about fragmented things can be transposed to the context of services. But each transposition takes the form of a question, rather like a riddle, because the things one knows about fragmented objects are not likely to be literally true of services.

For example one can ask, What are the fragmented services? Were they previously whole? How did they fragment? What does it mean for them to be made whole again—accessible under one roof, integrated in a single service-providing process (as when doctors and teachers work together to help a disabled child), or provided under the aegis of a single agency? What are the possible means and likely consequences of "making whole"? When two services are coordinated through the use of a single facility, for example, what can be projected as to their future use by clients and their influence on each other?

Such riddles give direction to inquiry. They help to determine what is worth investigating. Answers to them yield a new representation of the situation which defines the elements to be attended to, suggests their casual connections, and permits an inquirer to anticipate how the situation is likely to respond to intervention. By interrogating a generative metaphor, raising questions whose answers become hypotheses to be tested through further inquiry, the inquirer can elaborate a design structure, as in the following dialogue:

Teacher: Why do you say these services need to be coordinated?
Student: It's obvious.
T: Why is it obvious?
S: Well, clearly it's better for them to be connected together than fragmented.
T: What's lost if they're fragmented?
S: A number of things. For one thing, it's hard for a person, particularly if he is old or disabled, to get what he needs if he has to go to many different places and deal with many different agencies.
T: But this happens all the time. You go to one place to have your shoes repaired, another to buy insurance, and still another to have your teeth fixed. Are these services "fragmented," too?
S: It's not the same thing. Take the case of an old person who is blind. He's apt to have many other needs associated with his blindness. He may need medical care, help with transportation, training for a job, or psychiatric counseling. And these are likely to be connected needs. He is a whole person, with one interconnected set of problems, and he needs a service system that can respond to him as a whole person.
T: But were these services ever integrated in a single agency?
S: No, but that's irrelevant. The problem is to treat him as a whole person rather than as a series of disconnected needs.

Here, the student begins with the statement that services are better whole then fragmented, a statement whose obviousness rests on the as yet unexamined metaphor of fragmentation. The student first translates "wholeness" into "single access to different services," but rejects this idea when he sees that different services are often provided satisfactorily under multiple auspices. In his second attempt at translation, he suggests that it is the person, rather than the services, that must be made whole. And he rejects the proposition, also derives from familiar knowledge about broken things, that fragmented services must once have been whole. If he were to follow up this line of inquiry, he might go on to explore just what services need to be connected, and how best connected, in order to respond to the client as a whole person.

In order to create a design structure, it is not enough to make a metaphor, like the metaphor of fragmentation and wholeness, for the riddles generated by the metaphor may be answered in many different ways. It is the metaphor plus the dialogue of its translation that yields design structure.

These examples of the metaphorical generation of design structures are from the field of policy formation, and they contrast with such accounts as Lindblom's disjointed incrementalism. It is interesting to speculate on the ways in which generative metaphor might substitute for the model of random generation/programmed selection in other fields. For example, Poincare, in his model of the creative process in mathematical invention, already hints at a metaphorical explanation when he mentions his sudden recognition of similarity, first, between "the transformations I had used to define the Fuchsian functions" and those of non-Euclidean geometry and, subsequently, between the latter and "the arithmetic transformations of indeterminate ternary quadratic forms."[10] Although Poincare goes on to explain these sudden illuminations through the random generation and aesthetic screening of combinations of unitary concepts, his insight consists in seeing an unfamiliar set of transformations as a familiar one.

In place of Ogburn's "selective accumulation" of social customs, we might imagine a theory of societal change that would explain the generation of new cultural forms through the metaphorical transformation of existing cultural types—that is, through the idea of a cultural repertoire transformed through its transposition to a new context. Alexander's account of the evolution of new shawls is, in fact, vague enough to include a metaphorical explanation of development. The changes introduced by the shawlmakers might consist of just such transformations of familiar types as I have hypothesized in my discussion of a shawlmaker's learning from one trial to another.

How generative metaphor might become part of an account of biological evolution I do not dare guess—though I find the prospect intriguing.

In all these fields of design-like evolution, the idea of synthesis through generative metaphor raises many more questions than it answers. Some of these suggest interesting directions for further inquiry, as I shall illustrate in the area of social services.

How does storytelling reveal and elaborate generative metaphor?

Students are often surprised at the stories they tell, and even more surprised at how useful their stories turn out to be. Where do their stories come from? And why is storytelling so often accompanied by a sense of discovery? On one view, the storytelling context leaves us relatively unconstrained by fear of criticism, allows us to "speak before we have anything to say," and thereby enables us to tap into our store of tacit knowledge—things we have known about this situation and its relations to other situations but had not made explicit to ourselves. Or perhaps storytelling enables us to piece together bits of knowledge we already possessed but had never assembled.

We seem to possess a narrative or dramaturgical impulse to make sense of unfamiliar situations by telling stories about them. We continually seek to make sense of things strange to us by fitting them into versions of familiar stories. Hence, when we ask someone to tell a story about a new situation, we ask him to pay conscious attention to a sense-making process in which he is already tacitly engaged.

Given some such narrative impulse, is there a pattern to the stories we tell? Do we draw from a limited repertoire of stories which we adapt, now to one situation, now to another? How does the process of selection, fitting, and adaptation work?

It is intriguing to speculate on the counterparts to storytelling that function in contexts that lend themselves less obviously to narration, for example, graphic design. Just as we might imagine a designer of social service systems having access to a *repertoire* of metaphors from which he can generate problem-setting stories, so we can imagine a graphic designer having access to a repertoire of visual images any one of which can serve as a basis for the representation of a design situation. Stories and visual images may function like prototypes, each a source of a different way of seeing the situation.

How are generative metaphors found and selected?

Encounter with an unfamiliar situation provokes a search for connections with familiar ones. This is not Simon's search for paths to solution, but a search for ways of constructing design structures within which paths to solution may later be discovered. Nevertheless, it is search of a sort. Perhaps it takes the form of a scanning of the designer's repertoire of prototypical stories or images, prototypes whose use is characteristic of what might be called a "design culture" or perhaps of an individual designer's idiosyncratic style. Often, *we. find* ourselves with a metaphor, without having been aware of looking for one.

Common usage suggests that designers scan their repertoires for similarities between a new situation and situations represented in the inquirer's memory store. But in this respect common usage may be misleading. At first, we are more likely, in Thomas Kuhn's phrase, to perceive a similarity without being able to say similar with respect to what.'"[11] Only later, then a metaphor has been made—when we have already begun to speak of services as fragmented, for example—does the question of similarity arise. Then, as we consciously juxtapose fragmented services and broken bowls, we may arrive at explicit descriptions of their similarities and differences. This process may lead us to propose a general theory of fragmentation that includes among its instances both service systems and bowls. Reflection on the metaphor of fragmented services may work backward, as it were, to reshape our ideas about the sorts of things that may be whole, broken, and made whole again.

How do we come to select one generative metaphor rather than another? One kind of answer is semantic. The metaphor of fragmentation is already in our ordinary language; we are in the habit of describing things other than physical objects as broken or whole. But we are also used to other habits of metaphorical description—metaphors, for example, that hinge on the distinction between the natural and the artificial, high and low, strong and weak. What leads us to choose just *this* metaphor?

Another kind of answer draws on sociology of ideas. If we were to trace the idea of fragmented services to its origins, we would uncover a network of practitioners and analysts who have participated in a kind of social movement organized around the reform of service systems through coordination. Indeed, the very notion of "system," borrowed from the weapons systems of World War II, may lie somewhere near the origins of this movement. In the case of the metaphor of artificial institutions and natural communities, it may be possible to trace these ideas back to the eighteenth century and perhaps to an individual, Jean-Jacques Rousseau, whose theories of natural man corrupted by artificial institutions penetrated deeply into the mainstream of Western social thought.

In cases such as these, the use of a metaphor reflects the operation of social movements that have brought particular ideas of reform into currency. An individual may find himself thinking of fragmentation and coordination when he thinks of service delivery systems, without knowing how he came to do so, because that metaphor has become powerful for thought and action in the society of which he is a part. But more than one metaphor capable of influencing our thinking about reform exists already embedded in our everyday language and in our stock of ideas in currency. There remains the problem of understanding the interaction between broadly shared domains of language and ideas in currency and the thinking of a particular individual engaged in a process of design.

Is there a basis for saying that one metaphor is better than another?

Through generative metaphor, we set problems whose adequacy can be judged in terms of our ability to solve them. Have we set a problem we can solve? Beyond this fundamental question, however, we can also ask whether we have set the *right* problem. When we set the problem of service system design in terms of fragmentation and coordination, for example, we are apt to think exclusively in terms of existing services, without attention to their quality or their appropriateness to changing circumstance. Needs for services may change as social contexts change. Old people, for example, tend now to be deprived of the supports once provided by an extended family. Or the creation of new resources may provoke a change in perceptions of needs for service, as people learn, for example, to "need" the most advanced medical technologies. The metaphor of fragmentation and coordination may yield an inadequate problem formulation because it induces us to overlook such changing needs.

Each generative metaphor suggests particular strategies of selective attention and inattention. It is, in the final analysis, on the basis of our appreciative systems, the values we place on things attended to or overlooked, that we judge the adequacy of a way of setting a design problem.

Designing as reflective conservation

Once we conceive of designing as a process that begins with the designer's construction of an initial design structure, then we are also likely to pay attention to the ways in which design structures evolve. Having framed the reform of a service delivery system in terms of de-institutionalization, for example, we may discover, by trying to solve the problem we have set, just how inadequately we have framed it. The caring networks of natural communities may fail to materialize, once people are released from mental hospitals stigmatized as snakepits or from prisons vilified as schools for crime. The costs and difficulties of "community care" may appear overwhelming, once we actually try to implement de-institutionalized service systems.

From this perspective, the design process is a frame experiment.[32] Beginning with one way of framing the problem, derived from a particular generative metaphor, we invent and implement solutions whose unanticipated effects make us aware of the selective attention or mistaken assumptions built into our initial frame. We become aware of values we did not know we held until we violated them.

Our frame experiments are dialectical, or—as I prefer to say—they are "conversations" with the materials of a situation. When we frame a situation and create an initial design structure within which we begin to invent and implement solutions, we become newly aware of conflicts within our own appreciative system. In the extreme case, these conflicts may present themselves as intractable, and the design problem becomes a dilemma.

In the case of service delivery systems, design dilemmas may take quite predictable forms. Every service delivery system represents answers to questions such as these: who is to get what service? under what auspices? how are services to be funded, controlled, sequenced, and evaluated? Characteristically, answers to these questions consist in strategies that conflict with one another.

We tend to place a high value on the equitable provision of services, but under conditions of limited resources, a high priority on equity may mean that no one gets enough. In order to make service systems more consistent and efficient, we may opt for a strategy of centralization, which interferes with norms of responsiveness, diversity, and community participation, all of which militate toward a strategy of decentralization. For the sake of learning, we may emphasize small-scale experiments, which can be seen as discriminatory or elitist. A priority on quality may lead to an emphasis on professional expertise that conflicts with values of community control.

Sometimes, a designer becomes aware of conflicts like these as his design process unfolds; he discovers the narrowness of an original design structure as he tries to implement solutions derived from it. Sometimes a potential for conflict is inherent in the discrepant frames held by different designers. Then, in the literal sense of the word, designing can be understood as a "conversation," a dialogue among individuals who frame a design situation in different ways, employ different generative metaphors, operate from different appreciative systems.

For example, frame conflict may stem from the different perceptions of different professionals, all of whom are involved in designing; or it may stem from the different perceptions of interest groups who have different stakes in the design. To take a recent instance, the design of systems of medical care involves not only physicians, but providers like nurses and paraprofessionals, health workers' unions, health policy analysts, hospital administrators, health maintenance organizations, health insurance agencies, and advocates for special groups of patients like the elderly or the poor. Not only are participating groups likely to frame the problem of health service delivery in different ways; the very words used to describe problems and solutions are likely to have different meanings for them. So, for example, a word like "centralization" may hold connotations of efficiency for one group and coercion for another.

In their design conversations, participants often talk across discrepant frames, unaware that they are doing so. Apparent agreement can mask conflict that emerges later on, when proposed solutions are implemented. Disagreement can disappear when individuals discover what they mean by what they say. The discovery of an authentic design dilemma—one that owes its existence to actual frame conflict—may come as a result of individuals working hard to communicate with one another, learning to create the conditions for valid inquiry into one another's frames.

Once a design dilemma has emerged, it may be resolved or dissolved in a variety of ways. Resolution may take the form of an invention that satisfactorily meets requirements which had seemed, until the moment of invention, to be interactably inconsistent. Or it may take the form of a mixing of values so that all may be achieved at some satisfactory threshold, though none is optimized. Or a dilemma may be resolved by deciding that some values take priority over others. Utility theory offers a way of treating values as comparable and additive, translating the terms in which benefits and costs of alternatives are variously described into the common currency of utility. But utility theory does not provide a means for deciding among conflicting values judged to be incommensurable, or for resolving conflicts about the weights that should be assigned to different values.

Sometimes design dilemmas may be dissolved by reference to values that pertain to the process of designing itself. In a real-world setting subject to real-world constraints, there is an economics of designing, related to the allocation of scarce resources of time, energy, and intelligence. A typical event in the life of a design team is the discovery that the deadline for completion of the work is imminent and a solution must be produced. The resulting pressure for solution may trigger the invention of new design options, or it may provide an incentive for making hard choices that had been deferred or bypassed.

Designing, in the dual sense of dialogue among individuals and transaction with the materials of a problematic situation, is a process in which communication, political struggle, and substantive inquiry are combined. The adequacy of a generative metaphor, or the problem setting that results from its use, should be considered in the light of

the metaphor's functioning in the full process of design. A generative metaphor may be judged appropriate, for example, if it leads to the creation of a design structure that directs inquiry toward progressively greater inclusion of features of the problematic situation and values for its transformation. A good design process gives direction to inquiry while at the same time it leaves design structure open to transformation.

Conclusion

In this paper, I have explored the very widely and deeply held model of designing as rational decision, with its division of the design process into generation and selection, and its alternative views of generation either as random combination of given elements or as systematic search of a problem space. On the one hand, I have wanted to show how this model is entrenched not only in theories particular to the design professions but in theories of psychological, social, economic, and biological development built on the metaphor of design. On the other hand, I have wanted to identify sources of incompleteness inherent in the model. It cannot explain that initial creation of figurally complex design structures and options. It cannot account for the dialectical transformation of structures that we observe when we attend to the ways in which designers learn through designing. Hence, it is limited either to the special class of problems—for the most part, artificially constructed—where design structure is given from the outset, or to the later phases of actual processes where designing takes the form of technical problem-solving within a stabilized structure.

I have proposed an alternative view of designing based on generative metaphor. Here, the focus is on problem setting, as well as problem solving. The split between generation and selection no longer holds, for the metaphorical development of a design structure determines both the general character of options and the criteria by which to select among them. Designing is seen as a conversation with the materials of a situation within which new trials are often based on learning from earlier ones. It is seen, for the most part, as a social process in which different designers frame the situation in different ways and learn, when they are successful, to talk across divergent frames. The idea of a designer's repertoire of types, images, and metaphors plays a central role on this perspective, as does the idea of design dilemmas, on whose resolution or dissolution the possibility of problem solving depends.

From this vantage point, there are significant implications for the theory of designing, as well as for design education and the development of computer-based design assistants. Attention must now focus on the formation and reformation of structures within which unitary elements and relations are given. One can no longer rely on the positing of elements and relations, presumed to remain constant throughout a design process: only the least interesting processes conform to these conditions. One must account for the kinds of learning in which designers transform structure by implementing design proposals and continually see situations and options in new ways. One must forego objectivism and attend to designers' perceptual construction of new design entities.

Design education must give a central place to such processes as the framing of design situations, the development of a repertoire of types and images, skill in the metaphorical process of seeing-as, and reflection on divergent frames.

Once the figural complexity of actual design structures and options moves to center stage, it must seem extraordinarily ambitious to build computer programs capable of reproducing the cognitive complexity of actual designing. It is quite another matter, however, to envisage computer assistants for designers—computer environments able to track a complex design process, assist in handling the additive complexity of technical problem solving within a given structure, or provide access to a store of examples, images, and descriptions.

Finally, although an understanding of designing based on generative metaphor and conversation may no longer deserve to be called a "science" in Simon's sense, it can still contribute to an epistemology of professional practice. Simon's insight into the design-like character of practice holds true, even though the model of design as rational design does not.

Notes

1 Herbert Simon, *The Sciences of the Artificial,* MIT Press, Cambridge, MA, 1971.
2 *Ibid.* pp. 58-59.
3 *Ibid,* pp. 55-56.
4 A well-formed problem, in Simon's terms, is illustrated by the "diet problem," described below.
5 Gregory Bateson, *Steps to an Ecology of Mind,* Ballantine Books, New York, 1972.
6 Simon, *op. cit.,* p. 61.
7 As analyzed by Dr. William B. Schwartz, of the New England Medical Center, and by Anthony Gorry. The example given here has been taken from conversation with Dr. Schwartz.
8 Simon, *op. cit.,* p. 63.
9 Charles Darwin, *The Origin of Species,* Mentor Edition. New York, 1958; p. 55.
10 *Ibid,* p. 74.
11 William Ogburn, *Social Chan<&,* Viking Press. New York, 1922; pp. 76-

12 Adam Smith, *An Inquiry into the Nature and Causes of the Health of Nations,* Modern Library Edition. Random House, New York, 1937; origi nally published in 1776.
13 Christopher Alexander, *Notes on the Synthesis of Form,* Harvard University Press, Cambridge, MA, 1964; p. 50.
14 *Ibid,* pp. 53-54.
15 Charles E. Lindbolm, *The Intelligence of Democracy,* The Free Press, New York, 1963.
16 Donald S. Schon, *Technology and Change,* Delacorte Press, New York, 1966; pp. 78-79.
17 Henri Poincafe, "Mathematical Creation," in Brewster Ghiselin, ed, *The Creative Process,*Mentor Books, New York, 1955.
18 *Ibid,* p. 39-40.
19 *Ibid,* p. 40.
20 Most recent attempts to design computer programs that "learn" also depend on the existence of design elements and criteria of selection that are assumed to hold constant throughout the design process. For example, one popular model of "learning" programs employs probabilistic analysis to reinforce combinations of elements that are qualified, according to some established test, as "hits."
21 Simon, *op. cit.,* pp. 67-68.
22 *Ibid,* p. 69.
23 *Ibid,* p. 68.
24 Marvin L. Mannheim, *Hierarchical Structures: A Model of Design and Planning Processes,* The MIT Press, Cambridge, MA, 1966.
25 *Ibid,* p. 72.
26 *Ibid,* p. 75.
27 Martin Rein and Donald A. Schon, "Problem Setting in Policy Research," in Carol H. Weiss, ed, *Using Special Research in Public Policy Making,* Lexington Books, D. O. Heath and Company, Lexington, MA, 1977.
28 See Donald A- Schon, "Generative Metaphor: A Perspective on Problem Setting in Social Policy," Andrew Ortony, ed, *Metaphor and Thought,* Cambridge University Press, Cambridge, England, 1979.
29 Geoffrey Vickers, *Responsibility—Its Sources and Limits,* Intersystems Publications, Seaside, CA, 1980.
30 Poincare, *op. cit.,* p. 37.
31 Thomas Kuhn, "Second Thoughts on Paradigms," in F. Suppe, ed, *The Structure of Scientific Theories,* University of Illinois Press, Urbana, IL, 1974.
32 See Donald A. Schon, *The Reflective Practitioner,* Basic Books, New York, 1983.