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Design Reasoning Without Explanations

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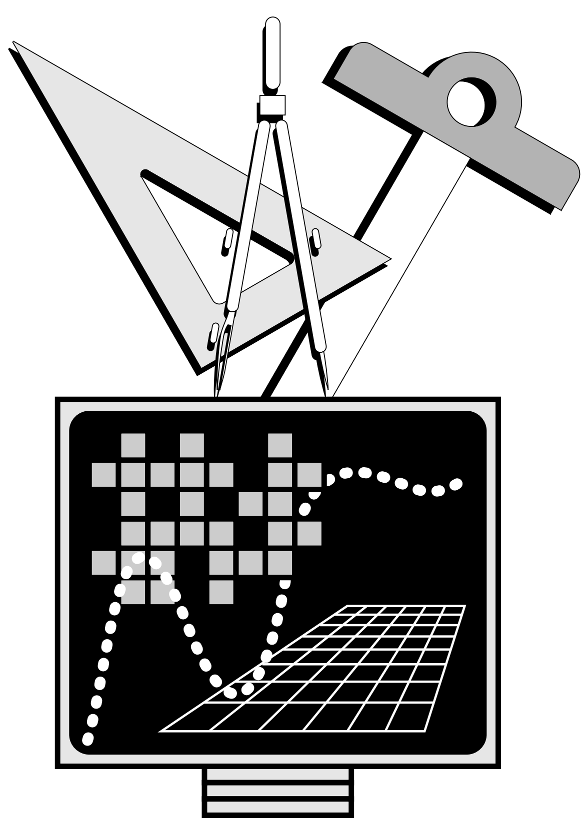
This article proposes connectionism as an alternative to classical cognitivism in understanding design. It also considers the difficulties encountered within a particular view of the role of explanations and typologies. Connectionism provides an alternative model that does not depend on the articulation of explanations and typologies.

The goals of design research are varied, and the sources of its methods of inquiry are diverse, calling on such areas as history, hermeneutics, sociology, psychology, philosophy, and computing. Irrespective of the genre within which the research is undertaken, we can legitimately ask, How does design research impinge on the practice of design? The most immediate impact would be expected in the area of improved tools and environments for designers. The tools might ultimately include resource material to facilitate decision making, such as textbooks, guides, codes, and computer programs. Environments might ultimately be systems of organization and communication that are tuned to the needs of designers.



However, the most important category within tools and environments is essentially of a different character. I refer here to the contribution of design research to the intellectual resources that facilitate discourse about design. Thus, one of the most important spin-offs from design research is the sets of terms, models, intellectual structures and, ultimately, the controversies that enable us to talk about design.

We might suppose that design would still successfully occur without these intellectual structures, as it does in many cultures today. Furthermore, insights could be expected to arise from the deliberations of design practitioners and critics whose activities do not come under the heading of research. However, there is obvious merit in articulating design, separating it from other concerns, and making it an object of study and carefully reasoned reflection. The resulting intellectual structures would be expected to benefit the fostering of design ability, both formally in design schools and as designers respond to their environment and each other. Thus, the products of design research are inexorably linked with design education.

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There is little doubt that design research involves considerable controversy. As well as inheriting the controversies from within the disparate genres of inquiry previously mentioned, design research has the potential to offend by impinging on our view of ourselves as creative individuals. In a climate of controversy, it is appropriate to ask, What are the benefits of the intellectual structures arising out of design research when there is so little agreement? The view propounded here is that we are bound to make judgments on the relative merits of particular models or points of view, and even the refusal to entertain a particular point of view can facilitate helpful discourse. Statements about what design is not can be as informing as views about what design is.

The ultimate questions to be asked of a view of design are, To what extent does the view facilitate discourse about design? and To what extent does a discussion of the differences, as well as the similarities, between this model and other models inform us about design? In this way, one of the quests of design research lies not only in discovering the truth about design but also in finding oppositions. We are informed by the clash of views.

The discussion to this point constitutes a preamble to the presentation of two contrary views that impinge on our thinking about design: classical cognitivism and connectionism. Both largely call on the methods of inquiry of cognitive science and computing. Both views are controversial, and both could be expected to be rejected outright by some within the design community. It is contended here, however, that both views substantially contribute to discourse about design because of the terms and constructs they make available to us and by the nature of the paradoxes they bring to light.

Design and Models of Cognition

The predominant tradition of design teaching (at least in the West) heavily depends on articulating ideas through spoken and written language. Drawings and the designed works themselves are considered insufficient as vehicles for imparting design knowledge. Observing design and doing design are also insufficient. We require that they be supplemented with words. Some of the features of the way we talk about designing are addressed by Schön (1982), with his characterization of reflection in action, and Rowe (1987). Although the popular idea of design discourse (or dialogue) is not merely limited to words, the process is imbued with a strong linguistic flavor.

There are major differences of opinion regarding the nature of design discourse. It is contended here that the advocacy of different views on the role of explanations leads to differences in attitudes toward design teaching. It is contended here that the content of the discourses held by partisans of different views might not appear substantially different. That is, what is said at the drawing board or even in the lecture room might be similar. The difference is manifested primarily in policy formulation and management: the discussion of design curricula, the way design programs are organized, and how the work of novice designers is evaluated.

These issues are brought into sharp relief in design teaching as well as when we consider how computers might be used in design. Apart from the practical uses that can be made of computer systems, there is the added benefit that the sharp focus provided by computer implementations allows us to critically test the consequences of our ideas. Computers allow us to take ideas to logical and, possibly, absurd limits. A clear example is the way in which computers can be used to implement theories about human problem solving and cognition. In the course of this discussion, I look at two different approaches to understanding human cognition. I use simple explanations of computer implementations to demonstrate how the ideas work and highlight some implications for design teaching.

The two preeminent models of cognition are classical cognitivism and connectionism (Clark 1989). *Classical cognitivism* focuses on the idea of symbols as mental representations. Much AI work exploits the utility of this approach, with its emphasis on rules and other explicit knowledge representation devices. *Connectionism*, however, focuses on implicit knowledge representation. It is concerned with modeling human reasoning at a low level in an attempt to replicate the capability of human reasoning to transcend the strictures of sharply defined categories and formal logic.

From the point of view of design, the interesting aspect of these theories is that each can be used to account for different aspects of design behavior, and each can be used to support different approaches to design. Classical cognitivism supports an emphasis on design rules, hierarchies of types, and the articulation of the design process. However, connectionism can be said to emphasize experience and the emergence of design ideas without attempts to articulate the process.

It is not the purpose of this article to advocate one view over the other or to preclude

> *Explanations are proffered to satisfy the critics, promote decisions, and persuade.*

other views. There are difficulties with both classical cognitivism and connectionism (Minsky and Papert 1969; Dreyfus 1981). This article mainly focuses on the problems with classical cognitivism and how they are avoided (or possibly ignored) by connectionism. Before considering these two approaches in detail, it is necessary to look at something of the nature of design discourse. Because of the enormity of the subject, I focus on only two aspects of this discourse: the role of explanations and the use of categories. What is said about these two issues can be seen as representative of the problems encountered more widely.

The Role of Explanations

Explanations appear to feature prominently in design activity. We seek explanations of the genesis and apparent evolution of designed objects. (Why does a doric column have a fluted shaft? How did the flying buttress come into existence? How do we account for the development of the Medieval piazza?) Apart from requiring explanations to satisfy their curiosity and analyze others' designs, designers are called on to offer explanations for their own decisions. Explanations are proffered to satisfy the critics, promote decisions, and persuade.

There appear to be several categories of explanation. Each enjoys varying degrees of acceptability depending on the context of the discussion. The following question is typical of what we might ask a particular designer (such as an architect): Why did you place a south-facing clerestory window above the living room? The acceptable explanation is usually of the kind that follows some line of argument, perhaps relating to lighting levels, sun control, the brightness of the interior, and even the psychology of people responding to and experiencing the space. A related kind of argument pertains to style: an appeal to the appropriateness of the architectural device (the south-facing clerestory window) to the particular architectural language. A variation of this kind of argument is an appeal to a commitment to the authority or influence of someone else: "I did it this way because I am strongly influenced by the work of architect X who strongly favors roof lights."

For most purposes, an unacceptable explanation is of the kind that appeals to an unsupported preference: "I always do it this way" or "I felt like a change." Least acceptable of all are explanations that appeal to feelings that defy detailed explanation. I return to the unacceptable kinds of explanations later. It is the acceptable explanations that I want to discuss here. They belong more to the tradition of design education.

There are two approaches to explanations. One is to accept that there is such a thing as a true or false explanation and that if a particular explanation is in error, then it can be proven to be so. The identification of a particular logic error should compel the designer to return to the task and revise the design. If it turns out that south-facing clerestory windows do not produce sufficient surface illumination or that clerestory windows are not part of the language of a particular style of architecture after all, then there is the compulsion to change the design.

There are difficulties with explanations when taken in this way. Obviously,there is a difficulty if explanations are seen to depend on apparently controversial or unsound theory, which is currently the case in using explanations that depend on theories about human responses to spaces. However, explanations also pose difficulties by the nature of argument itself. On close inspection, we see that explanations can involve us in an endless chain of reasoning as we attempt to form links between our conclusions and our assumptions, first principles, or empirical evidence. Furthermore, the details of explanations elude us as each reasoning step demands further refinement. The problem is well recognized in the Kantian critique of Cartesian rationalism. The flaky nature of explanations is further aggravated when we observe the human propensity to change explanations in preference to changing decisions. We also appear to exercise the ability to change our explanations according to the audience for our ideas.

Do these difficulties mean that explanations are invalid and undeserving of any credibility in discourse? The second approach to the value of explanations is neatly summarized by a quotation pertaining to one of the primary roles of language: "In using language we are not transmitting information or describing an external universe, but are creating a cooperative domain of interactions" (Winograd and Flores 1986, p. 50). As part of this discourse, groups of people exert influences on one another. In the context of professional design training, the flow of the cooperative discourse is such that there is generally some influence in favor of the conventions and norms of the particular design discipline. The discourse produces thinkers in harmony with the design discipline or disciplinary matrix of the day (Kuhn 1970). There is insufficient space here to enter into a full consideration of the challenge posed by the hermeneutic movement (Gadamer 1975; Rorty 1979) within modern philosophy to the instrumental view of language. This challenge is well presented by Winograd and Flores (1986).

The Role of Categories

Another weapon in the designer's armory, one that makes dialogue possible, is the notion of categories. Objects that are similar in some way bear the same word labels. Again, there are penalties in claiming that the categories we use reflect some objective reality. What actually constitutes particular categories is difficult to pin down, and definitions are notoriously elusive. In design, this difficulty is brought into sharp relief when we talk of *types* (Moneo 1978), which can be seen as generic descriptions of artifacts. Thus, in architectural design, we talk about the L-shaped kitchen, the courtyard house, the mausoleum type, the civic building, and so on. The identification and delineation of types is important. We create categories on the basis of certain similarities that are easy to recognize. Having devised an object in terms of a category, we can then talk of other properties known to belong to the type as a whole. The use of categories introduces economies into the discussion.

As with chains of explanations, the delineation of types leads us into difficulties, especially if we declare that typologies describe the reality of an external universe. Catalogs of types prove to be prohibitively large. The patterns of types and subtypes become complex and fluid. Before long, we find that there is, after all, no satisfactory meaning to the L-shaped kitchen and its infinite variants, either by the individual or society at large. Types and subtypes are also nested in nonconforming ways. The boundaries between types are fuzzy (What is the real difference between a church and a chapel?). No sooner do we establish neat typologies than someone invents an artifact that crosses the boundaries between several types.

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Designing

The use of explanations and types in design discourse appears to extend beyond analysis and criticism. Explanations and types feature in designing. Part of design discourse, particularly in teaching, appears to involve turning explanations and categories around. They appear to act as generative devices for producing design decisions. More precisely, they act as prescriptions to others about how they might produce similarly appropriate design decisions. It is as if we dissect our explanations into logical modules. Each module constitutes a piece of knowledge; so, designers sometimes talk in terms of rules: If you want lots of light, then put in a clerestory window; if you want to avoid direct sunlight falling on work surfaces, then orient the windows to face south (in Australia).

Types similarly appear in talk about generating designs. Design can be characterized as identifying the appropriate type for the particular context and then *instantiating* (exploring the scope of variation allowed by the type to arrive at a design instance).

We might suppose that these prescriptions form part of design discourse. They feature prominently in the advice given to novice designers. It is contended here that the discourse itself poses few problems, bearing in mind its role within a "cooperative domain of interactions" (Winograd and Flores 1986, p. 50). However, for some, it becomes important to promote the appropriate prescriptions and excise those that are false. This view can be realized as a search for design principles. For those for whom the quest is less illusive, the design principles can even be taught or put into a computer. However, as previously indicated, if explanations and types are friable, then their less certain use as prescriptions is even more so.

Classical Cognitivism

Computer-based design research that focuses on the importance of explanations as a source of knowledge generally feeds on models of thinking based on classical cognitivism. This view is characterized by an emphasis on symbolic representations and the manipulation of logical statements as capturing the essence of human reasoning. As discussed previously, the language of design discourse appears to trade heavily on logic and its variants. If true, with the computer medium, there is the evident possibility of the logic within human explanations and prescriptions being rendered operable. Much of the AI field and, specifically, that of knowledge-based systems seek to operationalize the explanations, rules, type descriptions, and prescriptions of human discourse. Recent accounts of the role of formal systems in design by Mitchell (1990), Coyne (1988), and Coyne et al. (1990) make substantial use of this paradigm.

Logical statements can be processed to prove or disprove an assertion or to produce new assertions, or we can use some kind of symbol-manipulating algorithm to generate combinations of design elements in keeping with a generative language. This approach is not entirely restricted to formal logic. Attempts have been made to capture the fuzziness of human reasoning and the creative ways in which humans apparently handle contradiction (nonmonotonicity) (de Kleer 1986). These techniques generally operate within the realms of explicit knowledge representation as rules. Similarly, knowledge can be brought to bear in selecting and instantiating within catalogs and hierarchies of types.

The apparent utility of these approaches lies in the idea that knowledge is made explicit and is open to scrutiny. The knowledge is of the kind that we invoke in much design discourse. The disadvantage is that we find we have captured something of the logic of the discourse but have captured nothing of the mediation of the human design agent. With the computer as design agent, the discourse can be checked for consistency and developed to its logical conclusions. The difficulty is that this checking takes place with a knowledge base derived from explanations, typologies, and prescriptions. These have been shown to be extremely friable. Meanwhile, the tacit knowledge of the human designer has eluded us.

There are at least three responses we can make to this difficulty. The first is to make do with the cautious application of explicit knowledge in automated design decision making. A second option, favored by Winograd and Flores (1986) and Bijl (1989), is to see the computer as a medium that facilitates discourse. Thus, the emphasis is on the human design agent. A third option is to focus on computational models that do not rely on explanations as opposed to models that focus on the structure of explanations and prescriptions. This latter provocative line is the one that is pursued here.

Connectionism

Because less attention has been directed at the implications of a connectionist view of cognition on design, it is worth looking at the ideas in some detail. Although the ideas within connectionism are compelling (from the point of view of their novelty if nothing else), there is no intention here to advocate its superiority to classical cognitivism. The intention is merely to present an opposing view. A feature of connectionism is that it skirts around the problems outlined in the previous sections.

In contrast to computer models that exploit the manipulation of symbols as a metaphor for human problem solving, connectionist models emphasize the structure of the human cognitive hardware. In spite of the potential complexity of this approach, certain models have been proposed that render the general idea accessible (Rumelhart and McClelland 1987b). In essence, the connectionist approach abandons the idea of working with explicit knowledge representations. Although rules and type definitions serve in the logic of design discourse, they are not at the heart of design processes. The connectionist models that are proposed rely heavily on the notion of memory and the belief that decisions emerge from this memory in response to some situation. The mechanisms by which decisions emerge rely on information-storage techniques and algorithms that are thought to model biological mechanisms, albeit in a pale way. (See Coyne and Postmus [1990] for an introduction to connectionism in the context of design.)

A major assumption behind the approach is that aspects of extremely large and unfathomably complex systems, such as the brain, can be studied to good purpose in a much scaled-down version. Thus, the connectionist approach involves the construction of computer models that consist of *networks* (connected nodes [units] with certain numeric attributes, generally, linkages and threshold values). These models are intended to capture aspects of the readily observable electrochemical behavior of groups of neurons. Rumelhart and McClelland (1987b) present empirical evidence that they argue strongly supports the plausibility of the models. Connectionist networks are claimed to exhibit properties that could be considered essential features of human cognition: the idiosyncratic way they learn, their reliance on memory, their ability to deal with partial information, and even their pathologies. Here, we explore a further possible claim: that they exhibit a propensity for behaving in a way that captures the essence of design. They appear to synthesize, to innovate.

The idea is best explained with an example, using one particular connectionist network model. The example is trivial but demonstrates the basic idea. The example has been implemented and is technically explained by Rumelhart et al. (1987) and explored in the context of design by Coyne, Newton, and Sudweeks (1989). A connectionist network is trained about a set of rooms. In this model, each of the possible features of a room is represented as a node on the network. (There is no suggestion that concepts map onto individual neurons in real brains.) The features are descriptors, such as the fact that there is a sofa in the room or that the room has a large window, a carpet, or a refrigerator. There are 50 possible features and, therefore, fifty nodes in the network. Each room is presented to the network in turn; that is, when the system is presented with room 1, its features are activated on the network. An algorithm is applied to make adjustments to the parameters of the network (actually weights on the connections between the units and threshold values on the units). These adjustments ensure that if at a later time the network is presented with a partial description of this room, then another algorithm will bring the original pattern of activations to life. The system has a rudimentary kind of memory.

Subsequent rooms are presented to the system. The system learns these patterns as well. The memory capability of the system is realized if we present the system with a feature such as a sofa, and the system brings to life other features such as an armchair, carpet, or standard lamp. If we activate the refrigerator, then we would expect the stove, sink, and floor tile features to come to life. In other words, the system is able to recollect examples given to it on the basis of fragments of information. Already we see something that appeals to our way of thinking about cognition: A simple idea can trigger a complex recollection.

This ability to learn and recall is interesting and useful but becomes more significant when the system is taught a large number of room examples (perhaps 60 or more). Some of these examples might be different from one another, some similar; so, there might be several room examples with sofas, but each might display slightly different characteristics. The weights and thresholds that make up the memory of the system begin to interfere. What happens now when the system is required to recollect a room with a sofa in it? A description is produced that resembles a typical sofa-bearing room. The system has not produced a general sofa room description but a typical case. The algorithm that facilitates this recall can also be induced to summon other room descriptions that are less typical. According to the system, the most typical room example might contain a sofa, an armchair, and a carpet. If we tell the system that the room also contains a bed, then we can induce the system to find a typical room that contains a sofa and a bed. This room might be different from the one with the armchair and carpet. This kind of recall facility is fundamentally different from conventional database approaches. The room descriptions are not locally stored in any particular part of the network but distributed across the whole network. As well as having a certain appeal on the basis of what is known about the distributed nature of human memory, this phenomenon leads to certain generative properties.

This approach becomes extremely interesting when we force the system to produce a description of a room that is not in accordance with any of the examples; for example, we tell the system that the room has a sofa and a sink. We find that the system generates a description of a room (a combination of features) that we might recognize as a studio apartment. What has happened is that the system has accounted for all the connections between descriptors to arrive at the most mutually compatible combination of descriptors. If we look at the operations of the system at the algorithmic level, what has happened is wholly unremarkable. The system has not had to struggle to invent a new room type. The algorithm that simulates recall in fact implements a kind of relaxation procedure. The system settles into a state of activation that is consistent with the parameters (the weights and threshold values) set up during the learning process. Recalling an imaginary room required as little effort as recalling a familiar room.

As stated previously, the example is a trivial

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one, and here we do not have the persuasiveness of the detailed implementation at our disposal. (See Coyne [1990] for an example pertaining to simple foundation design in buildings and Coyne, Newton, and Sudweeks [1989] for details on the furniture layout example.) Further levels of sophistication can be contemplated if we extrapolate this experiment to allow units in the connectionist network to pertain not to features describing rooms but to any combination of concepts. We soon run into the limitations of this particular model. However, if we assume that this model bears some resemblance to aspects of human cognition, then several valuable observations can be made:

First, the system does not require explicit type definitions or type boundaries to demonstrate generalizing behavior. At no stage was the system told any of the labels we normally attach to room types (such as bedroom, bathroom, or kitchen). However, the system behaved as if it was governed by typological knowledge.

Second, no rules are presented to the system, yet it can behave as if there are rules: All rooms with beds have a wardrobe. Further experiments have indicated that as well as making generalizations, such systems retain information about exceptional cases (Rumelhart and McClelland 1987a; Coyne and Newton 1990).

Third, significant from the point of view of design, such systems can cross the boundaries between implied type descriptions to produce novel but consistent combinations of features. This faculty appears to be a major human quality not addressed by symbolically oriented models.

Fourth, the process by which descriptions are produced, except at the trivial computational level, is distinctly void of logical explanations. If we see the system as a rudimentary kind of problem solver (what goes with a bed and a sofa?), then the solution simply emerges. In some cases, the explanation would have to be, "I remember such a combination of elements." Because the system might never have been exposed to its own solution before, the more general explanation is, "The answer is consistent with my experience."

In summary, the connectionist models provide structures for considering ideas important to design: the use of precedence and the emergent nature of much design reasoning. The connectionist models provide ways of accounting for this behavior without recourse to the explicit representation of rules and type hierarchies.

Implications for Understanding Design

How do the implications of connectionist models of cognition impinge on how we understand the design process? Leaving aside any argument about the superiority or veracity of either classical cognitivism or connectionism, we can see that a commitment to one or the other could promote tendencies toward particular approaches to design understanding. Thus, the value of these models is that each provides us with vocabularies and conceptual structures for enlivening design discourse. As indicated in the following discussion, connectionism provides a structure for talking about aspects of design that might previously have eluded us.

Classical Cognitivism

The approach of classical cognitivism provides a structure for considering the following aspects of design: (1) the importance of rules, (2) the study of typologies, (3) the importance of explanations, (4) the establishing of evaluation criteria, and (5) the use of computers.

The first aspect of design emphasizes the importance of rules. This view takes seriously the notion of explanations as a source of generative knowledge. We should not only teach the theories that pertain to the effective analysis of designs but also decision-making principles and procedures. In light of the elusive nature of rules and their heuristic nature, this view can be modified as a quest by individuals to discover their own rules and methods. There is also considerable benefit in making this knowledge explicit as tables, diagrams, reports, and flowcharts.

Second is the study of typologies. The definition of terms used by designers is important so that we have a common base for discussion, which extends to the definition and study of typologies. For example, the study of building types and their evolution is an important part of architectural history, primarily as source material for our own designing.

The third aspect involves the importance of explanations. Design decisions must be justified. Designs should be modified in light of proven inconsistencies in explanations. There is a tendency to take explanations given by successful designers at face value.

The fourth aspect involves the establishing of evaluation criteria. The presuppositions on which explanations and decision are based should be made explicit. Making presuppositions explicit is important to establish where an argument begins and ends when all the logical statements are strung together.

Fifth is the use of computers to support this process. The knowledge by which design decisions are made can be put into a computer and made operable. Shortcomings in such a knowledge-based system are addressed by providing the system with more knowledge and more sophisticated control structures.

Connectionism

The approach of connectionism provides a structure for considering the following aspects of design: (1) the importance of precedence, (2) intuition, (3) the articulation of design knowledge, and (4) the belief that new ideas can emerge from prosaic ideas.

The first aspect of design is the importance of precedence. Exposure to events and instances is important. A rich experiential base is required to facilitate design reasoning. Learning to design by doing and observing is important. Observing without generalizing has a role in education, as does copying. Familiarity is the best teacher.

The second aspect is intuition. This view accepts that certain design activities cannot be externalized. It accepts the fickle nature of explanations as they are used to justify design decisions. It accepts that aspects of design and design teaching defy traditional academic and scientific treatment. It gives credit to the power of persuasion that extends beyond the compulsions of logic.

Third is the articulation of design knowledge. It accepts that much is imparted in design education that cannot be made explicit. It is pluralistic and accommodating to different views and coteries of expertise that enliven and extend the cooperative domain of interactions.

The fourth aspect is the belief that new ideas can emerge from prosaic ideas. The ability to create is inherent within the human cognitive hardware. One of the prerequisites for a successful creative endeavor is a thorough grounding in the conventional.

Conclusion

The jump from a theory of cognition to its practical outworking in understanding design is bound to be hazardous. Here, I chose the safe course of maintaining that different paradigms of cognition enrich the way we talk about design. Their influence on how we actually do design poses even greater difficulties. The language of the connectionist paradigm allows such ideas as emergence to be discussed within a framework. The lesson from connectionism is that computational models exist by which we can describe apparently informal operations. Connectionism challenges the advocacy of formal rigor in design by offering a formal model that in fact supports an informal view of the design process. This challenge presents us with an attractive basis for a deconstruction. Like most interesting ideas, these propositions inevitably contain the seeds of their own destruction.

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