DUAL-BASIS DESIGN

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Abstract

Dual-basis design is a response to those shortcomings in the science and practice of large-scale system design which are represented by frequent catastrophic failures in such systems.

Among the primary shortcomings are underconceptualization of the design science and of the design practice, and the failure to base design practice upon design science.

An upgrading in these areas (already completed through a first iteration) will make possible the application of a concept of "due process" in design. This will provide a practical and legal basis for identifying and monitoring responsible management practices. This may lead, over time, to substantial improvements in practices, which will in turn lead to more reliable designs, a lower rate of catastrophic design failures, better correlation of outcomes of design with situational requirements, and elimination of much of the waste that currently characterizes large system designs.

Terminology

Design

Design is a process that is directed purposefully toward some ultimate change in a situation. This process is informed by some basis of preconceptions. The basis is often implicit. When it is implicit, it may be because those who have such a basis are not able to articulate it.

The basis of preconceptions may include some that are specific to a particular situation. However there will also be some that are relevant to many design situations [1,2]. And certainly there must be some that are relevant to the design of large-scale systems.

Target

A target of design is the outcome sought as a consequence of a design process. While both the process and the target are often called "design", it is best to eliminate the ambiguity by having one term to represent the process and another to represent the desired outcome of the process.

Design Science

A design science should consist of foundations, theory, and methodology, interacting in a particular way [3]. Specifically, foundations focus the theory. Theory explains the concepts and laws that are invariant in carrying out design. Theory also provides ratioinale for defining criteria to be met by acceptable design methodology [4]. Methodology furnishes the components from which the process of design is devised.

Design science provides the basis for all decision-making that occurs in the design process that is not situation-specific. This includes both decisions about how to manage the process and decisions that must be made within the design process. Design science may also extend its influence into areas that are situation-specific. Design science of the latter type can be called specific design science, while design science of the former type can be called generic design science.

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Misconceptualization

Since design is a highly conceptual activity, it is subject to misconceptualization, i.e., to an embedding of errors both in the recursive effort of designing a design process and in applying a design process to design a target other than the design process.

Underconceptualization

Underconceptualization is a prominent form of misconceptualization. It is characterized by the omission of important concepts, either in the process of design or in the description of the target. Such underconceptualization may affect adversely any of the following: development of a design science, comprehension of a design situation, development of the description of the target, and the means of or manner of implementing or installing the target.

We may speak of "technomyopic science" or "technomyopic behavior" as a way of accounting for underconceptualization in any of these aspects. As is well known, myopia is a defect in vision so that objects can be seen distinctly only when very near the eye. By extending this concept with the term "technomyopia" in order to reflect a more general interpretation, we gain a term that refers to inability to perceive distinctly things that are remote from the imagination. Just as the presence of myopia contributes to the inability of the viewer to detect inability to see distant objects, so in the larger sense the inability to perceive distinctly things that are remote from the imagination conceals from the victim of this disease a knowledge of its presence and impact. As a consequence, those who are guilty of underconceptualization are shielded from the knowledge that they are doing so.

Gasparski [5] has called attention to the importance of the "theory (or philosophy) of methodological orientation (attitudes) of the designer". Also he has indicated that designers need at least three kinds of skills which he calls "receptual, transformational and communicational". Of these, the type of skill that is most needed to avoid underconceptualization is the receptual skill. Since technomyopia, by definition, is a self-concealing disease, it is only through receptual skills that the designer who is a victim of this disease can possibly overcome the impact of it and thereby hope to avoid underconceptualization.

Due Process

Due process is a concept that is recognizable in academic and legal circles. Typically it is relevant in situations that require action to resolve an issue. In such situations, certain process features must be present, to ensure that omissions do not occur that are judged valuable in reaching an equitable resolution of an issue.

It is also understood that the exercise of due process is not a guarantee of an equitable solution; rather it is an indicator that previously-recognized defects in process will not be permitted, by themselves, to assure an inadequate airing of the relevant information.

While due process is a foreign concept to large-scale system design, one must now assert that it should play a dominant role in such design. The high and growing incidence of bad designs [6], especially of bad large-scale system designs, reveals clearly to those who study the history of these incidents that underconceptualization has been a major factor in the catastrophes that have been a consequence of bad designs. Morever there is evidence that the designers lacked or did not exercise receptual skills.

Therefore it is now becoming necessary to make visible a concept of due process, as a means of setting standards for processes of large-scale system design to help prevent unnecessary catastrophes that ensue from bad design. As is customary in present practices in other fields, failure to exercise due process will be the basis for sanctions of various kinds, the specific nature being dependent on the gravity and consequences of the offense.

Evidently the delineation of due process will require integrated theoretical and empirical considerations. The ideal approach would involve a design science that contains methodology that is supported both by foundations and theory and by appropriate empirical tests related to the foundations and theory. In the absence of direct testing in past design situations, post mortem analyses may be made that compare the observable causes of failures with the results of experience in using the design science. At a minimum such comparisons will serve to counteract the self-serving arguments of those who insist that design not be subject to any articulated discipline, no matter how benign or open it may be to creative behavior.

Candidate Situations for Introducing Due Process

Certain highly-visible areas of design are candidates for introducing due process. These include defense systems involving very expensive, publicly-funded designs like those that continue to fail to meet situational requirements [6]. An especially relevant area pertinent both to U. S. defense and commercial markets is the computer software area. Recently Brooks [7] published a discussion of the factors that are possible avenues for improvement. He suggested that truly major improvements are not likely to be achieved. Brooks recommended the development of superior designers, but did not say how to achieve this. The U. S. Department of Defense proposes to make major investments in billions of dollars worth of software without any basis in design comparable to what is proposed here. Nuclear plant design and operation is another highly-visible candidate for the use of due process, unless the impact of past failures wipes out such activity altogether.

It is important to have areas such as these to use as tests of the design science, for it is well known to scholars of science (but not to most technologists or business leaders) that its development is iterative; and requires close, frequent, and detailed interaction between a science and its applications as a means of continually upgrading quality in both. While at present this is a neglected responsibility in the situations mentioned, the introduction of due process to design, based on design science, offers a means of correcting this.

In a later section, the software situation will be discussed further in order to correlate a general discussion of design science and dual-basis design with some specifics.

Top-Down Design

It is intended in this paper to describe a concept called "dual-basis design" as a core idea in improving design science and practice. This concept was introduced in earlier papers [4,8]. Dual-basis design is an extension, an enhancement, and a contributor to the definition of what has loosely been called "top-down design".

Top-down design is often advocated as a means of countering underconceptualization. It is argued that, by starting at the highest level of generality available for a specific design situation, one can help assure that the full spectrum of conceptualization that is needed will be introduced at the beginning, and will serve as a continuing disciplinary agent on the design process. As this approach, over time, leads into progressively more specific detail, the design can be protected from technomyopic behavior.

A critical shortcoming in the present practice of top-down design lies in its failure to reflect priors of the design process. If the design science itself has not been developed using a top-down philosophy, its application to a specific top-down design situation will likely produce the very kind of technomyopic result that the application of top-down design to the specific case is said to help avoid. Moreover, the situation then is even more difficult to contend with, because the design is advertised as having been carried out from a sensible philosophical base, even though it lacks substantive realization in design practice.

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Dual-Basis Design Concepts

The twentieth-century concept of very large systems to be developed by people (and to include people), and which are dependent on synergistic interaction of people and machines or on people and processes for their success, requires a reconceptualization of design in a way that is compatible with the concept of sociotechnical systems.

For such systems, people and artifacts share responsibility for doing things that neither alone could accomplish at all, or could only accomplish in a very inefficient or low-grade way.

Examples of failures in such systems keep coming to the fore, where failure is superficially attributed to "operator error" or, more generically, to the people component alone, or (less frequently) to the technical component alone, without acknowledging that the problem is fundamentally a failure of system design stemming from inadequate conceptualization of the underlying science.

A basis for design consists primarily of the foundations and theory that make up part of design science. The foundations consist of those concepts that have no relevant priors, no ideas that are both relevant and more fundamental. The theory takes these foundations as the means of distinguishing what is and what is not appropriate to be elaborated for explaining design.

A dual basis for design involves foundations and theory that stem from two distinctive origins, as opposed to a single origin.

Just as top-down design is intended to begin at the highest level of generality for the specific situation, so top-down design of design science must begin with the universe itself, in order to reveal the bases and to avoid uncerconceptualization.

For these reasons, among others, scientists typically partition the universe into large, distinguishable blocks. Such partitions channel thought, provide a way to organize knowledge by disciplines, and promote intellectual sanctuaries that nurture cultural canals. Those scientists who have a strong aversion to anything that does not involve numbers tend to work implicitly with such a partition, not acknowledging overtly its existence, but being highly conditioned by it nonetheless. Clearly this is an inferior approach to science. It is only by exposing the underlying assumptions that either correctness or serious flaws can be determined.

One partition that dominates much scientific thinking implicitly splits the universe into two blocks. The first block is the set of all living human beings. The second block is what remains after the humans are conceptually eliminated from the universe. The social sciences take the first block as their territory, and physical sciences take the second.

Such a partition, which may serve both institutionalized physical and social science rather well, is totally inappropriate as a basis for the design of sociotechnical systems. For this purpose a different partition of the universe is needed.

The new partition that has been offered to serve the needs of design (and other applications) has been called a "Cosmic Partition" [2]. Instead of partitioning the universe on the basis of the living humans and the rest, this partition uses as a means of making the distinctions the sources of information in the universe. This partition contains three blocks, defined as follows:

- The <u>Library</u>: which contains all information that is expressed in any recorded form, using any kind of medium (print, magnetic tape, etc.)
- The <u>Phaneron</u>: identified long ago [9] by C. S. Peirce as "the collective total of all that is in any way or in any sense present to the mind, quite regardless of whether it corresponds to any real thing or not"
- The <u>Residue</u>: which represents the contents of the universe once the Library and the Phaneron are excluded from it

In the language of semiotics, the Library contains signs viewed as items, ranging from individual characters to large aggregates of literature or exposition. The Phaneron consists of both significats and interpretants, both being viewed as signs.

The first of these is the way the originator views the meaning of the sign in relation to the object for which the sign is surrogate, and the second is the way a receiver views the meaning of the same sign. The Residue contains objects, many of which are denoted by signs in the Library or in the Phaneron or both. Individual objects in the Residue may be represented by many signs scattered throughout the Phaneron.

Congruency in language is a situation where the object itself, an item in the Library, a significat and an interpretant in the Phaneron all convey the same meaning. Congruency is a rare occurrence, but it is especially important in design. If it cannot be achieved, the transformational and communicational skills identified by Gasparski as two of the three requisites of the designer cannot be effective and originate many errors.

The Phaneron involves subsets. We may describe that part of the Phaneron which is bounded by or delimited to a single human being as a phane. The Phaneron itself, or a subset consisting of a collection of phanes, can be called a polyphane.

Generally speaking, each phane is unique, and has been described also as the individual's Gestalt, as the individual's world view, and as the individual's virtual world. But none of these terms flows naturally into larger sets, as does the phane. The information contained in any phane consists of some which can be scientifically validated, and some which cannot be, and is characterized by C. S. Peirce as "laden with an immense mass of cognition already formed, of which you cannot divest yourself if you would." This description is particularly important in respect to design, because it is necessary in some way to divest from the description of the target any invalid knowledge that may otherwise be retained to lead to a flawed design. And one must remember that technomyopia is not capable of self-correction.

Critical to design science is the quality of information that is applied. The implicit working assumption that the mind is an unconstrained instrument that sometimes lacks tools to deal with the complexity inherent in objects in the Residue can be replaced with the broader recognition: complexity is the union of the difficulty inherent in the phane of the perceiver and those attributes of the object in the Residue that make perception difficult or impossible. [Compare, for example, with Brooks' [7] statement about how complexity resides in software].

Combined Sociotechnical Basis

Dual-basis design can now be described as design that is informed by a design science that uses an integrated basis of social and technical information in a manner elaborated with respect to the second of the two partitions discussed.

In particular, this foundation must deal with such things as limitations on individual phanes; processes designed to pool the validity of polyphanic information while eliminating the invalidity; enhancing the quality of signs appearing in the design process and its outcomes; promoting congruency; and discovering the proper role of technology in overcoming or circumventing limitations of the Phaneron [10-13, 20].

A first iteration of such a science of design has been exhibited [2,14,15]. It gives an example of a dual-basis design; namely its own construction. It is, itself, designed with a dual-basis foundation. For ease of remembering and making distinctions, one can talk about three "ogicals" as three possible bases: anthropological, technological, and logical. The anthropological incorporates the Phaneron, and the logical incorporates the Library and the reception and interplay of ideas in the Phaneron whereby new ideas are produced therein. The technological, on the other hand, represents those aspects that relate to the eternal referents of physical science; those primary standards that discipline engineering and manufacturing and provide the basis for all physical measurements.

The technological forms the basis for application of physical science, although it is not clear that this is advisable for the health of it. But the anthropological and logical form the dual basis for generic design science. In the absence of eternal referents in these areas, the validity enjoyed by physical science must find surrogates that spur the same degree of universal understanding, and provide comparable discipline to the science and its applications.

Many applications of this generic design science have been reported, and their number is constantly growing [16]. The experience accumulated in these applications provides means of continually re-validating the science and adjusting its assertions to reach a higher grade of congruence.

This reported work, of relatively recent origin, and appearing in proceedings of systems conferences or journals as a rule, tends to escape the purview of disciplinary specialists. The work is mostly unknown to most people who engage in building or growing or otherwise making sociotechnical systems or components of them. Because of the urgency of developing better designs in such areas, and the indifference of disciplinary specialists to this situation, it is important to pick a particular area that is widely visible as a potential proving ground for the science. One such area that is appropriate is the computer software field.

Dual-Basis Design Applied to Software

High-level computer languages inherently present high structural complexity to a phane which is limited in its powers of recall by the low capacity of short-term human memory. A numerical measure of complexity related to such languages has been given, based on what are believed to be reasonable characterizations of the capacity of a phane to work with information [17].

The factors in software productivity improvement cited by Brooks [7] offer a good panorama against which the need for and application of dual-basis design can be assessed.

Brooks' ideas are strong wherever the first partition of the universe is relevant, and weak wherever the second is needed. To illustrate the point, Brooks' comments on graphics can be cited:

> "Sometimes the theorist justifies the approach by considering flowcharts as the ideal program-design medium and by providing powerful facilities for constructing them...Nothing even convincing, much less exciting, has yet emerged from such efforts. I am persuaded that nothing will."

The graphics typically offered by the present software development community [18] are likely to deserve the criticism offered by Brooks. Nevertheless at least two arguments can be given to cast considerable doubt on Brooks' views. It is somewhat strange that the first of these emanates from a report of a Task Force on Software of the U. S. Defense Science Board chaired by none other than Brooks [19]. This report states that the reason that software technology has grown so slowly is that the essence of the difficulty has not been dealt with:

> "...the essence is designing intricate conceptual structures rigorously and correctly; further methodological improvements will have to attack the essence--conceptual design itself"

If we accept this view of the matter, one must recognize that there is a potential conflict in Brooks' own views. A flowchart, properly prepared and defined is nothing more than an "intricate conceptual structure". Flowcharts, and other forms of relation maps, rest on the foundation provided by the Theory of Relations initiated by De Morgan in 1847, and subsequently developed to a high state of applicability specifically to facilitate "designing intricate conceptual structures rigorously and correctly". Furthermore, it is the experience gained with the use of this development that has provided the underpinning for many tests of the generic design science. Moreover, as used in this science, many intricate conceptual structures have been produced and, in the process, new light has been shed on situations that are complex. Designs have been created rapidly for several of those situations, using the dual-based science that rests on anthropological and logical foundations; but which also employs technology in its methodology along lines indicated as necessary by the dual-basis concepts.

Some of the elaboration needed to clarify further the arguments advanced can be found in [20-22]. But it is appropriate to mention here the following aspects of dual-basis design thinking:

(1) The representation of thought requires the capacity to portray the structure of an issue, which implies the use of hierarchy, stages, and cycles [20]. Local logic in which two concepts are directly related is distinguishable from deep logic [22] in which the relation between two concepts is indirect, and may involve numerous levels or stages of intermediate logic.

(2) Human mental capacity to work efficiently with hierarchies, cycles, or stages when limited only to mental operations is extremely limited. Thus, for effective use of deep logic, visible portrayal of structure is essential.

(3) If language of portrayal is restricted only to prose forms, without the benefit of accompanying graphics, the representation of structure deteriorates rapidly as the depth of the logic increases.

(4) If language of portrayal is restricted to combinations of prose and formal mathematics, the potential readership is immediately restricted to only that very small fraction of the population that happens to have mastered the particular formal mathematics that is employed.

(5) One branch of mathematics, namely the Theory of Relations and its mathematical colleague, the Theory of Sets, provide the formal language needed to portray structure. Statements in natural language can be expressed in the algebra of logic, as can groups of relations. All such statements can be expressed formally in the Theory of Relations. But statements in the Theory of Relations can be mapped directly into binary matrices. Computers can manipulate filled or partly-filled binary matrices to work with and transform large aggregates of knowledge and structured knowledge [20].

(6) Machines can compute digraph structures directly from binary matrices. Such structures can be based on individual (atomic) relations or on composite relations as expressed in the binary matrices. Automatic documentation can be generated dirctly from either the algebra or from digraph structures, expressed in natural language with controlled syntax. Metrics can be computed, based on these knowledge structures, and these metrics can be correlated directly with human capacity to construct, learn, and interpret such structures.

(7) Because of the variety of translatable forms in which representations based in the Theory of Relations can be given, great flexibility is available to construct, learn, interpret, and amend these forms, and thereby enable communication about complex systems. In this way, every human being becomes a potential participant in design, and every designer can use natural receptual skills which, by themselves, cannot assure that what is to be received is so presented as to be receivable.

What has been offered in this set of aspects of dual-basis design thinking is a way to gain an overview of what is important in, for example, setting a course for the future of software and of the whole information industry. It is necessary to construct or reconstruct design theory on these dual-basis concepts. With this recognition comes the capacity to command the full powers of logic in a way that is compatible with human mental capability, human reception, and human interests. And from these concepts the due process requirement will be readily discernible.

Conclusions

A vast challenge awaits recognition and action. This is the challenge of constructing in its full utility a science of design that has a dual basis, being rooted both in integrated logical and social considerations. Such a science will be applicable to the sociotechnical systems that we may, at some time, decide we need to design.

The resources needed to take on this challenge are readily at hand in several areas of potential application, and especially they are available to the software enterprise.

Continued neglect of this challenge will lead to predictable outcomes such as frequent catastrophe, loss of competitiveness and further erosion of the economic base of society.

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