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DESIGN THEORY ADVANCES AND MEASUREMENT SCIENCE

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Abstract: The paper considers the significance of Design Theory in Measurement Science. It presents a modern view of design as a knowledge acquisition and transformation process. A brief outline of the classical model of design is provided. A model of the design process as a knowledge transformation process, based on a board architecture is proposed. A view of design concepts as models, and of design concept generation and transformation as a problem solving process, is presented. Reference is made to practical examples.
Keywords: Measurement Science, Design Theory, Artificial Intelligence

1 INTRODUCTION

Measurement and Instrumentation Science is the systematically organised body of knowledge, with general concepts and organised, generic, transferable principles, which underlie the technology of measurement and instrumentation. The nature, scope and structure of Measurement and Instrumentation Science have been reviewed systematically in [1] and [2].

It has been argued that design theory is a basic component of Measurement Science. Measurement problems are essentially the problem of design of a measuring system, [1], [2], [3]. There is an extensive literature on design theory. Classical design theory has been reviewed analytically in [4], and its application to instruments in [5]. The classical perspective on Design Theory presented in this literature is founded on the methodology of Systems Engineering and on the methodology of mechanical machine design. There have been, in recent years, significant and fundamental advances in the understanding of design. These advances have been driven, particularly, by advances in software systems engineering [6] [7] [8], in knowledge engineering and artificial intelligence, [9]. [10] [11] [12], distributed information processing, and the development of concurrent engineering [13] [14].

The present paper is concerned mainly with conceptual advances in design theory. In particular it examines the model of the design process

2 DESIGN

A modern perspective on design views the design process as a knowledge acquisition and transformation process. It transforms knowledge about a primitive requirement, a set of statements in a knowledge description language, into knowledge necessary to implement or realise an artifact or system intended to meet that requirement

3 CLASSICAL MODEL OF THE DESIGN PROCESS

A model of the classical design process is outlined here in accordance with [5}. This model is framed using to some extent modern concept of knowledge and knowledge processing, but is in essence a classical model.

Classically design activity is represented as a process consisting of a sequence of stages, starting at the perception of need and terminating at the communication of the final firm knowledge necessary to implement or realise the artifact, or system. Each stage is itself an elementary design process, which starts with an initial concept and refines that concept. The stage is a sequence of steps, sub processes or operations.

Consider the elementary design process in the classical model (Fig. 1).

The initial step of the process is that of definition: of an initial design concept to be refined. The model and related knowledge is, in general, provided by the previous stage of design. Associated with this model is a set of evaluation criteria, or value model, which express the degree to which the concept meets the requirement

The next step in the process is the generation of a more refined candidate design concept. The generation of candidate design concepts is central to the design process. The candidate design concept is represented as a configuration, that is in terms of attributes of its construction. It is next analysed to determine its performance attributes and evaluated using the value model previously established. A number of such design concepts are normally generated and stored.

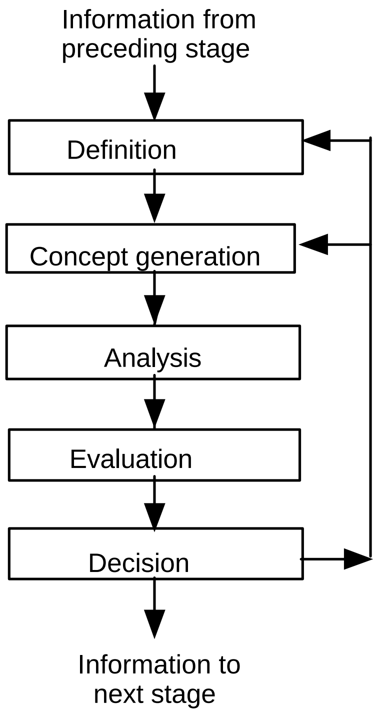

Figure 1. The classical model of the design process

The evaluation step passes information to a decision step where the candidate design concept judged to be the most satisfactory is accepted for implementation, or as the initial concept on which the next stage of design will be based.

If none of the candidate design concepts are acceptable, it may be necessary to return to an earlier stage in the process, for example, to alter the value criteria, or to generate more candidate design concepts.

Viewed overall, design proceeds from a global view of the artifact or system, to progressively more localised considerations, and from abstract and fluid descriptions, to concrete and firm ones.

The design stages typically start with a definition of the overall system which arises from the original requirement. This establishes the main features of the system as a set of interconnected subsystems, and also fixes the nature and specifications of the subsystems. In turn, the subsystem design stage uses this information to establish the main features of the subsystem and the nature and the specifications of its simpler components. This sequence of stages proceeds to the design of elementary components. If at any stage it appears that it is not possible to meet the specification generated by the preceding stage, it is necessary to return to an appropriate point of that latter design stage.

The classical model may be seen to have significant deficiencies. The model does not adequately take account of the flow of knowledge and the place of knowledge sources. It is based on the concept of top-down design and fails to accommodate the process of middle-out design, the reuse of designs and incremental development of design concepts. It also does not adequately represent processes, in which different parts or aspects of the system are being designed concurrently, and where the design activity is distributed and different parts of the system are designed collaboratively by different agents. An adequate modern model of the design process must adequately take into account all the above aspects of design.

4 A MODERN MODEL OF THE DESIGN PROCESS

A model of design activity is proposed here as a conceptual framework for understanding and organising design. It is to be understood that the architecture presented here is a 'logical' architecture and does not imply a particular 'physical' or tool support architecture.

The model is shown diagrammatically in Fig. 2. It is based on the concept of a blackboard architecture [9].

The core of the model is a board. The board is a global, structured knowledge base. All solutions generated in the design activity are recorded on the blackboard. They are organised by the board structure according to their levels of abstraction.

The model proposed here has different levels of linked boards. They are linked to the different levels of decomposition of the design. The top level records system solutions, the bottom level records elementary system components, the intermediate levels record sub-system sub-sub-systems and like intermediate levels of system decomposition.

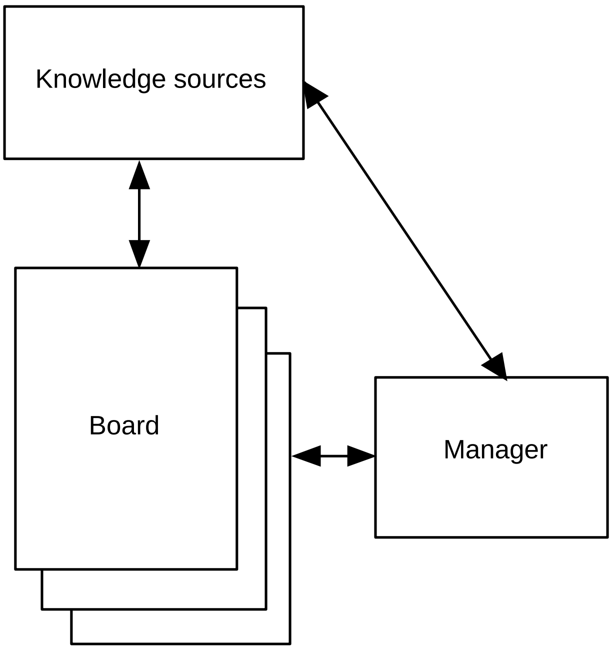

Figure 2. Knowledge based model of the design process

Design elements are generated and recorded on the board by knowledge sources. The knowledge sources are loosely coupled. They consist of declarative knowledge sources such as physical laws, component models and the like, and procedural knowledge sources, of the condition-action form, such as design methods. The knowledge sources collaborate by communication through the board.

The manager, or scheduler, controls knowledge source activity, taking decisions on the elements of the design.

The model supports top-down, middle-out and bottom-up design. It allows for concurrent design of various parts and aspects of the system. It also allows for reuse of partial solutions and the representation of incremental improvements.

5 DESIGN CONCEPTS AND THEIR TRANSFORMATION

In the above model the design process operates on a progressive transformation of design concepts.

A design concept is a set of design solutions, having certain significant attributes in common, one member of which may satisfy the design requirement. Design concepts are models.

Design concepts are represented in the form of models. The essence of the model is the choice of the form of knowledge representation used in the model. The nature of models specifically used in measurement and instrumentation have been discussed in [16].

It is convenient to represent design concepts in the form of the set diagram shown in Fig 3. The outer rectangle represents the design space, the set of all possible design concepts, determined by the design specification. The ellipses Ci represent two possible initial design concepts. Co represents the adopted design solution.

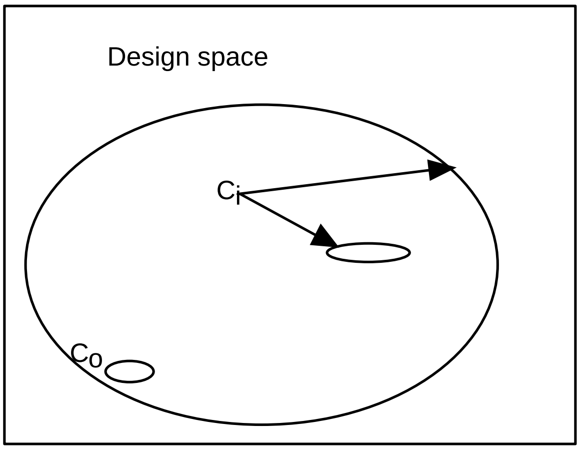

Figure 3. Design Concepts

The design process is the transformation of Ci into Co.

If Co is a proper subset of Ci, the process of design is convergent, If Co does not intersect Ci, the process of design is divergent.

It is convenient to adopt the problem solving paradigm to view the design process, [9]. Figure 4 illustrates the principle.

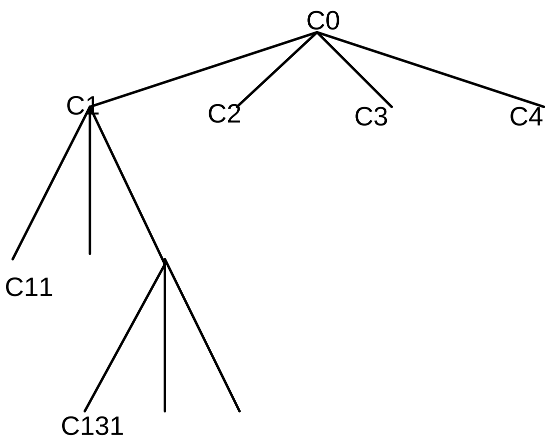

Figure 4. Search tree

The figure illustrates a tree, in which the node C0 represents the initial design concept constituted by the design space. C1, C2, C3, C4, and the like represent design concepts, which are subsets of C0. C11 is a design concept which is a subset of C1. C131 is a subset of C13, and so on. One of the nodes at the end of the tree constitutes the design solution.

In the design process we generate, analyse and evaluate a design concept. We thus proceed in accordance with concept generation, analysis and evaluation steps of the classical design process model.

The solution search may proceed top-down, bottom-up, or middle-out. In top-down search we start at the design space, generate more detailed solutions, develop them until we reach a final solution. In bottom-up search we start with a detailed final solution, and proceed upwards through more general concepts, to test whether the initial detailed solution adequate satisfies the design requirements. In middle-out solutions we start from an intermediate design concept and search both up and down the tree.

The model accommodates different search strategies. A depth-first strategy searches from the initial design concept, along a particular branch down to the node representing a candidate solution. A breadth-first search proceeds first by exhaustively generating and testing all design concepts at a particular level of abstraction, selecting one and then generating, analysing and evaluating all developments of the selected design concept and so on.

Convergent design is a search along a single branch of the tree. Divergent design is a search which moves from one branch to another.

6 DESIGN DEFINITION

A design is determined by the definition of the design space, which arises from the determination of the requirements.

The present paper does not permit a review of the the present state of requirements engineering, which is a significant component of design theory. It will confine itself to discussing the view of design definition in terms of the knowledge engineering model of design presented above.

Design definition is the establishment of the initial candidate design. It takes the form of a model of the system or artifact, which would satisfy the requirements. It may also contain the specification of some non-functional attributes.

Associated with this model is the definition of evaluation criteria, enabling the utility of alternative candidate design concepts to be evaluated. These criteria also embody constraints.

7 APPLICATIONS

The present paper has been concerned principally with conceptual advances in the model of the design process and of design concepts and their generation.

Extensive practical applications of these concepts are discussed in [10], [11] and [12].

In the field of application to the design of measuring systems, an agenda for appropriate research in the field has been has been presented in [17] and [18].

The application of search procedures using a knowledge base of design for the design of sensors have been reported in [19] and [20]. Work on the construction of knowledge bases for the design of sensors has been reported in [21] and [22].

8 CONCLUSIONS

Advances in the concepts of knowledge engineering and artificial intelligence have led to significant developments in the model of the design process, design concepts and design concept generation. The representation of design concepts as models puts emphasis on methods of modelling of measuring systems and their components, and on the use and further development of appropriate knowledge representation schemes. These new conceptual frameworks represent a contribution to the development of Measurement Science.

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