

Abstract of Interests in Design from Physical Principles

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My research interests are in conceptual design, design for quality, and optimization. In the area of conceptual design I have two projects where reasoning from first principles becomes of primary importance.

1stPRINCE

The 1stPRINCE methodology was introduced by Cagan and Agogino (1987) to generate innovative designs where innovative designs are defined as those designs in which new variables or features are introduced relative to a known set of variables or features. The design problem is formulated as an optimization problem of engineering first principles. 1stPRINCE uses optimization information to identify sets of active constraints which model optimally directed designs, and to determine how to expand the design space to introduce the new variables or features.

Expansion techniques manipulate the mathematics of the problem formulation, thereby introducing new design variables. One of these techniques, called Dimensional Variable Expansion - DVE (Cagan and Agogino, 1991b) expands the design space in a serial fashion; a different technique called Input Variable Expansion - IVE (Aelion, *et al.*, 1992) expands the design space in a parallel fashion. Expansion is not done arbitrarily; rather critical variables are identified from optimization information and an appropriate expansion technique is then selected. The expanded design space is searched and new designs are evaluated. Induction techniques are also introduced to examine the constraint activity over generations of design expansions to determine the limiting solution of the design process (Cagan and Agogino, 1991a). The method requires a proper formulation of the initial design model.

1stPRINCE has been used to derive solutions to problems in various domains. A class of hollow tubes and composite rods were derived from a solid round rod under torsion load to minimize weight; the same rod under flexural load leads to tapered beam solutions and I-beam solutions. A wheel was invented from a rectangular block to minimize resistance to spinning. Aelion, *et al.*, (1991) derived the solution for a plug flow reactor (PFR) from the initial design of a well-mixed reactor (CSTR) to maximize conversion; under different conditions, a sequence of reactors in parallel were generated also to maximize conversion. Other applications generated a powder catalyst from an initial sphere to maintain surface area while minimizing weight, and a sequence of columns were designed from a single column in order to generate a *feasible* design from an initially *infeasible* design. 1stPRINCE is thus able to generate new design topologies by reasoning from first principle information.

Shape Annealing

1stPRINCE is able to derive new components. A bigger

question is how to generate a new overall topology. *Shape annealing*, introduced by Cagan and Mitchell (1992), models the first principles as a *shape grammar*. Concepts of simulated annealing are then used to generate optimally directed solution shapes.

The shape annealing algorithm executes by applying a shape rule to an initial design. If the modification improves the design based on an objective it is accepted. If it generates an inferior design then it can still be accepted with a certain probability which is a function of the number of iterations executed; toward the beginning of the process almost all inferior solutions are accepted and as the algorithm progresses, only those solutions which improve the objective are accepted. In shape annealing, previous designs can be regained if they are superior; for every rule that modifies a shape, there is a complementary rule that removes that modification. Thus, shape annealing is an *evolutionary* design technique to explore the exponentially large number of possible design configurations. Inferior solutions are pursued to get out of local minima and optimally directed design topologies are derived. Shape annealing is being applied to layout problems, structural design problems, and machine configuration problems.

Related Papers

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