EVOLUTIONARY DESIGN OPTIMIZATION: TOOLS AND APPLICATIONS

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The present thesis responds to the worldwide attention given to numerical Structural Optimization, resulting from the need for powerful tools for generating better design solutions at lower development costs and the increasing availability of the necessary computational resources to support automated optimization processes.
The thesis focuses on the optimization of real-world structures, highly constrained by functional, manufacturing, or esthetic demands. Such optimization problems, where the search space may include both discrete and continuous search domains, often result in non-convex and noisy solution spaces. This makes the use of Evolutionary Algorithms (EAs) favorable, whereby their main drawback, i.e. high computational costs, can be mitigated by efficiently adapting EAs for the problems at hand. Thus, this thesis establishes evolutionary design optimization for highly-constrained mechanical structures in modern product development processes. Concepts, tools, and applications are presented, highlighting the potential of a smart integration of Evolutionary Algorithms into modern CAD/FEM software systems, and thereby overcoming some of the limits of traditional optimization approaches.
The basis is laid by the implementation of a generic Evolutionary Algorithm, based on the open-source framework Evolving Objects. For the parameter optimization, an universal genotype is introduced together with adequate evolutionary operators. It allows to efficiently address optimization problems consisting of an arbitrary list of heterogeneous parameters such as reals, integers, booleans, etc. The proprietary developed software DynOPS is implemented to rate the mechanical properties of the evolved structures with adequate fitness values, allowing for a parallel evaluation of individuals in an EA using arbitrary simulation software controllable through input files. Furthermore, a generally applicable formulation of fitness functions is proposed that simplifies the computation of scalar fitness values based on objectives and multiple constraints. Finally, based on the representation of mechanical structures in CAD systems, i.e. hierarchical feature trees, new genotypes consisting of lists of CAD-features are implemented and adequate evolutionary operators are developed. The resulting Evolutionary Algorithm is directly implemented into the optimization workbench of the CAD system CATIA V5.
Four applications demonstrate and verify the presented concepts: The weight of a well-established motorbike frame is reduced by 20.8% while preserving the originally desired mechanical properties. Minimizing the weight of a piston pin of a racing engine yields a new design, saving 11% of the weight of the original pin. For the optimization of a racing car rim, a parallel DynOPS EA-loop is successfully applied to a complex mechanical structure highly constrained through regulatory, functional, and manufacturing demands. Finally, the performance of CAD-driven EAs is highlighted by the weight minimization of an end plate of a fuel cell stack under strength constraints, yielding intuitively not expected but highly efficient design solutions.