PhD Project

Title: Evolutionary Search and Exploration

Research Subject

Evolutionary computation is widely applied in research and development and its potential for optimization tasks in the present of hard technical problems is demonstrated in various publications. Especially in the area of design optimization impressive examples are available in which existing designs are considerably improved. Furthermore, evolutionary computation has also been successfully used in early stages of the design and the development of systems. In opposite to the design optimization in which a very detailed model is optimally adapted to the given conditions, the task is the identification of a basic configuration within the overall design space.

Although evolutionary algorithms are in general capable of exploring the design space, current algorithms focus mainly on the optimization of a given quality criterion in a highly restricted area of the design space. The determination of conceptionally different and innovative solutions is still the domain of human experts. One reason is the high computational cost of a search in high dimensional spaces. Ways to circumvent this problem are either the mentioned restriction of the search space or the simplification of the problem formulation. In the later case, a common method to foster the exploration of the design space is the strengthening of random components in the algorithms. Although an improvement of the ability to explore the design space can be achieved, a directed and efficient search cannot be upheld purely by random modifications. It would be necessary to guide the search towards unexplored areas of the design space and away from already evaluated areas in an efficient way.

A similar problem can be identified in the area of robotics in which the system has to learn from experiences. The task is to identify search space areas which are unexplored up to know and which include potential solutions. A complete sampling of the search space is not possible, and the generation of new training data has to be based on an initial identification of promising areas in the search space [1].

A suitable way to solve the problems is the integration of concepts like novelty and interestingness which allow to define criteria to direct the search and thus facilitate the exploration of large design spaces [2,3].

The aim of this project is to research new concepts for exploration and for novelty detection in the area of design optimization. Three dimensional volume and surface descriptions have to be adapted to an optimal shape with respect to a predefined quality function. In opposite to the classical design optimization the target is not the fine-tuning of the design of an existing solution but the detection of innovative design concepts.

Therefore, it is necessary in a first step to evaluate the novelty of a design with respect to already known solutions and to detect examples of solutions with distinct properties. First studies in which novelty measures based on model prediction errors and learning progress rates have been already performed and demonstrate the suitability of these measures as additional criteria to direct the search.

In the following step a classification of the search space in design regions is necessary. Starting point will be the utilization of the same local models which incorporate the knowledge about special properties of a design space region or other phenotypic properties.
In particular the analysis of phenotypic properties in order to judge the novelty of solutions seems promising. For example in design optimization, the two and three-dimensional flow field of shapes and structures could be analyzed (possibly with techniques from image analysis) in order to detect major transitions in the solution space. In order to have a more tractable problem than computational fluid dynamics, possible toy problems could be the parameterization of differential equations (e.g. reaction-diffusion equations) for pattern formation. Transitions between characteristic patterns could be regarded as exploration for novel solutions in the parameter space.

During all phases of the research special considerations have to be given to two additional constraints, which are characteristic for real world problems. Firstly, the high dimensional design space in which the search has to be performed. Secondly, the high evaluation costs a sampling of the design space provokes by e.g., the detailed CFD analysis, i.e. optimization can only work with a restricted budget of function evaluations. The required balance between design space exploration and limited budget of function evaluations will be one of the key areas of investigation during this project, potentially requiring additional concepts such as local metamodels to be considered within this project.

The three years PhD project is roughly subdivided into three work phases:

Integration of novelty measures in evolutionary computation methods (1st year)
- literature review on exploration capability of evolutionary algorithms
- translate concepts like novelty, interestingness and curiosity to the area of evolutionary computations
- prediction of measures of eg. novelty for unexplored search areas including an update of the predictor with new design space samples
- analysis of novelty measures based on the phenotypic characteristics (flow fields, patterns)
- integration of the prediction in the evolutionary search process
- exploration of the suitability of multiple criteria optimization and/or niching methods to the design for novelty task

Classification of search areas (2nd year)
- generation of local models of the design space
- determination of design concepts based on the generated models
- the approximation of the design space by an ensemble of models representing different design concepts
- usage of phenotypic and genotypic characteristics to distinguish between novel and known solution subspaces

Application and verification of the researched methods to a real world problem (3rd year)
- integration of the developed methods in a framework for the optimization of aerodynamic properties of flow bodies
- comparison of different methods for novelty detection on test problems as well as the design optimization problem
- writing up of thesis

