Fuzzy Sequential Space-filling Design

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In engineering problems, often high-fidelity simulators are used to approximate black box real-life systems. These simulators evaluations can be very expensive in terms of computing time which makes their usage for optimization or design space exploration impractical (Gorissen et al., 2007). To lift this limitation, often these simulators are approximated by a *surrogate model*. This cheap to evaluate mathematical expression is constructed with a minimal number of (expensive) simulator evaluations.

A specific combination of the input parameters is known as a *sample*: the choice of samples for evaluation (*experimental design*) is crucial to the quality of the surrogate model. The samples can either be determined prior to evaluation and modelling (*one-shot approach*), or added sequentially. The latter avoids the risk of evaluating too many or too few samples. This process is halted when a target accuracy is met and is known as *sequential design*.

One of the main requirements of any experimental design is space-fillingness in order to maximize the amount of information captured by the samples. Space-fillingness is often expressed in terms of intersite distance (distances between each sample and it's neighbours) and projective distance (projection of the samples on each dimension should be as uniform as possible). Latin hypercubes are a very popular method because their projective properties are guaranteed to be optimal (Simpson et al., 2002). Optimization can provide good intersite distances, but unfortunately this can be a very lengthy process. This also that implies adding one or more additional samples requires the process to be restarted and results in a different design which disallows usage of Latin hypercubes for Sequential Design.

For a given design, the intersite- and projective distance combined result in a (very) difficult optimization surface. Several methods for sequential design were proposed earlier to avoid straightforward global optimization (Crombecq et al., 2009). These methods are inapplicable for problems of higher dimensionality because they are either Monte-Carlo based (and would require a lot of points) or require a lot of memory.

Modifying the objective function and applying concepts from Fuzzy optimization produces a better optimization surface. Instead of working directly with crisp values for the intersite distance and projective properties this approach results in a smoother optimization surface which allows a global optimization strategy such as Particle Swarm Optimization to identify a solution with a low risk of getting stuck in a local minimum. Experiments show this approach is fast and obtains good results.

References

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