Innovization: A Multi-Objective Optimization and Data Analysis Procedure for Unveiling Innovative Design Principles

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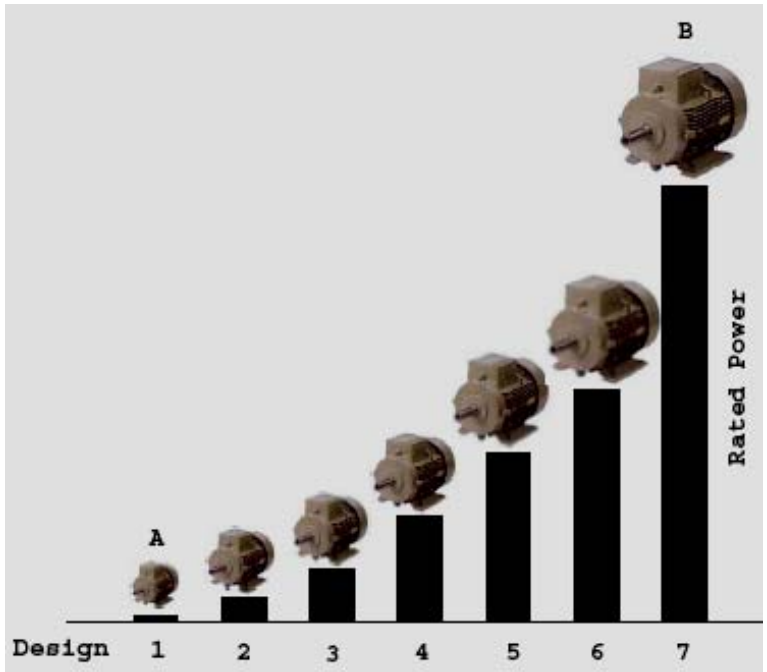
Innovization:
Innovation Through Optimization

Often we seek for an optimum, but here we attempt to understand important design principles in a routine design scenario

- Example: Electric motor design with varying ratings, say 1 to 7 kW
  - Each is a trade-off betn. size and power
  - What makes the trade-off?
  - How are they different from each other?



A task to discover 'What makes a solution optimal?'

Proposed Innovization Procedure

- Choose two or more conflicting objectives (e.g., size and power)
  - Usually, a small sized solution is less powered
- Obtain Pareto-optimal solutions using an EMO and verify them using other methods
- Investigate for any common properties manually or automatically

- Scientific basis for innovized principles: All optimal solutions must satisfy Fritz-John conditions:

$$\sum_{m=1}^{M} \lambda_m \nabla f_m\left(x^*\right) - \sum_{j=1}^{J} u_j \nabla g_j\left(x^*\right) = 0,$$

Innovization: Deriving conceptual version of math above

Why Innovization Can Produce Human Competitive Results?

- Not about finding one optimal solution in one problem, as done routinely
  - Often, a single-obj. optimum is uninteresting and specific to the objective
  - Although human-competitive, it may be an isolated scenario
- Hunting for properties of multiple trade-off optimal (high-performing) solutions
  - More reliable and relevant information
- Engineering and scientific systems follow fundamental physical/chemical principles
- Optimal solutions are special points in the search space
- They are expected to have isomorphic properties
- A generic procedure of extracting hidden properties which are needed to qualify a solution to be optimal
- Properties of optimal solutions not intuitive from math. problem formulation

Human Competitive (cont.)

- Innovized design principles are priceless and often not human conceivable
  - Out of 29 variables in a gearbox design, a monotonic increase in module alone with desired power output ($m \propto \sqrt{P}$) produces optimal designs
  - Out of 7,024 genes, only two are responsible with a reasonable confidence for two variants of Leukemia
  - In a crane operation of lowering loads, initial consecutive thrusts and lowering load suddenly at the end are time and energy efficient principles
  - In a chemical process plant, certain quantifiable charging patterns of three ingredients for optimal operation
- In all cases, unveiled innovized principles were not known earlier

Why This Entry is Worth the Prize?

- Proposed innovization task goes beyond finding one or more optimal solutions in a specific problem
- It allows one to *learn* about a system
  - How to solve a problem optimally?
  - Single optimum cannot reveal much insight
  - Users gather more insights about his/her system
  - Better inventory management, identification of important parameters, knowledge on alternate high-performing solutions, etc.
- A holistic use of optimization (made possible through evolutionary approach)
- No other known method for a similar task

Summary

- It is a procedure with demonstrated abilities of discovering human-competitive results on many different problem-solving tasks
  - It is more than a single human-competitive result on a particular problem
- Possible through evolutionary computing and EMO
- A triumph of optimization for a bigger cause
- No known competing procedure
- Should get popular in practice