POLITECNICO MILANO 1863

ENVIRONMENTAL INTELLIGENCE LAB

Thesis title

Reducing complexity in many-objective water resource optimization problems through linear and non-linear dimensionality reduction techniques

Short description

Water resource infrastructure systems are under increasing pressure to meet multiple demands and constraints which often conflict. In its search for Pareto-optimal solutions, multi-objective optimization can reveal the structure of trade-offs and synergies between multiple demands and constraints. While using a greater number of objectives has been shown to find more innovative and adaptive solutions in complex real-world water resources systems (Kasprzyk et al. 2016), the modeler (or the analyst) faces two problems: 1) computational tractability of many-objective problem formulations, and 2) involvement of decision makers in the exploration and visualization of the obtained solutions. Dimensionality reduction is a promising way to address these challenges. Examples of applying dimensionality reduction to address problem 1 include Pozo et al. 2012; Saxena et al. 2013; Shang et al. 2014; Guo et al. 2016. Yet, problem 2 remains relatively underexplored, and both problems have limited attention in the water resources literature. Such techniques, usually taking advantage of machine learning to exploit statistical relationships among the objectives, come at the cost of information loss but with the upside of greater algorithm reliability and greater consistency and diversity in solutions (Giuliani et al. 2014, Kaspryzk et al 2016).

The student is expected to carry out the following activities:

1. Literature review: reviewing the state of the art of many objective optimization for water resources systems, with specific focus on the following issues:
   - Computational tractability of many objectives problems;
   - A priori dimensionality reduction to facilitate the search phase;
   - A posteriori dimensionality reduction to facilitate the interpretation of the obtained solutions;
   - Implications of both on solution ranking and stakeholder preferences and connections to Arrow's paradox for aggregate objective formulations.
2. Computational experiments: analyze the space of the objectives of a simple water system case study using state of the art methodologies (e.g., simulation and sensitivity analysis / machine learning techniques / evolutionary algorithms) with the following goals:
   - Compare/contrast existing or develop novel method(s) to formulate a more compact problem using linear and non-linear dimensionality reduction techniques.
   - Develop novel means of presenting and communicating discovered traits in dimensionally reduced many-objective problems.

Relevant courses and knowledge: Natural Resources Management

Number of Students: 1 or 2

References

Giuliani, M., S. Galelli, and R. Soncini-Sessa. 2014. "A Dimensionality Reduction Approach for Many-Objective Markov Decision Processes: Application to a Water Reservoir Operation Problem." Environmental Modelling and Software[R] 57 (July): 101–14.

Guo, Xiaofang, Yuping Wang, and Xiaoli Wang. 2016. "An Objective Reduction Algorithm Using Representative Pareto Solution Search for Many-Objective Optimization Problems." Soft Computing 20 (12): 4881–95.

Kasprzyk Joseph R., Reed Patrick M., and Hadka David M. 2016. “Battling Arrow’s Paradox to Discover Robust Water Management Alternatives.” Journal of Water Resources Planning and Management 142 (2): 04015053.

Pozo, C., R. Ruíz-Femenia, J. Caballero, G. Guillén-Gosálbez, and L. Jiménez. 2012. “On the Use of Principal Component Analysis for Reducing the Number of Environmental Objectives in Multi-Objective Optimization: Application to the Design of Chemical Supply Chains.” Chemical Engineering Science 69 (1): 146–58.

Saxena, Dhish Kumar, João A. Duro, Ashutosh Tiwari, Kalyanmoy Deb, and Qingfu Zhang. 2013. “Objective Reduction in Many-Objective Optimization: Linear and Nonlinear Algorithms.” IEEE Transactions on Evolutionary Computation 17 (1): 77–99.

Shang, Ronghua, Kun Zhang, Licheng Jiao, Wei Fang, Xiangrong Zhang, and Xiaolin Tian. 2014. “A Novel Algorithm for Many-Objective Dimension Reductions: Pareto-PCA-NSGA-II.” In 2014 IEEE Congress on Evolutionary Computation (CEC), 1974–81.

Requisites: The student should be comfortable with data handling (Matlab or R) and programming skills (Python or C++).