Dynamic optimization under uncertainty

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Decision-making in real-world scenarios is inherently dynamic, sequentially alternating actions and reactions as uncertainties reveal themselves progressively and the state of the system mutates relentlessly. Models and consequent mathematical tools should adapt to uncertainty, adjusting in response to unfolding information. This work presents how to deal with sequential uncertainty and decision-making processes in diverse domains including engineering, retail, and manufacturing, and showcases different methodologies to dynamically map observed data to optimized decisions.

We begin by presenting a unified framework, introducing formalities and notations that connect the core of sequential decision-making processes across various domains. This provides the groundwork for understanding the complexity and adaptability required in the face of evolving uncertainties.

Then, we move to an engineering application, where we study the optimal mechanical control of a Wave Energy Converter (WEC). Though effective to an extent, traditional models can sometimes oversimplify complex systems for computational complexity reasons and lack of knowledge of dynamics of the system not observed or difficult to abstract. To deal with uncertainties coming from the behavior of the sea, where the device operates, and other system mutations, we propose a data-driven methodology. In particular, Gaussian process regressions and Bayesian models, which integrate computational modeling with online observations, are adopted to learn the parameters of a reactive control strategy. The framework results in a flexible control mechanism capable of enhancing energy harvest by rapidly adapting as more data becomes available, speeding up the learning phase.

In retail applications, we address the problem of efficiently managing inventories of perishable items like fresh food in single- and multi-echelon systems, with single- and multi-product assumptions. Uncertainty about consumers' behavior, coupled with the perishable nature of certain goods, demands a tailored sequential decision-making strategy. We use simulation-based optimization strategies, presenting adapted and enhanced versions of well-known replenishment and allocation policies to deal with substitution between and within a product category. Then, we focus on the complexity of multi-channel systems where online and offline retailers coexist and require decisions that take into account the correlation between channels, asymmetrical

demand distributions, and different characteristics of each retailer. Results show how simple parametrized policies can be tailored and effective both in replenishment and allocation decisions. Moreover, the benefits of taking into account substitution patterns in multi-product applications and inventory pooling in multi-echelon multi-channel ones emerge.

Lastly, we present an application in manufacturing, investigating Assemble-To-Order (ATO) systems. Here, the uncertainty on demand for items is shifted to the component level. Components are only assembled post-demand observation, generating risk-pooling effects. We use data-driven stochastic programming models, providing insights into the trade-off between the complexity of the model and actual performance. We show how extending the planning horizon is not always a guarantee of superior results. Moreover, we introduce a method based on hybrid policies made of stochastic programming lookahead approaches enhanced by approximate dynamic programming strategies, successfully overcoming the myopic effect of short-sighted solutions that fail to plan production in complex demand scenarios subject to seasonal peaks and correlation.