Chapter 12
The Optimizing Web:
A Green ICT Research Perspective

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ABSTRACT

There is a global consensus on the need to reduce our collective carbon footprint. Improving the efficiency of how we use our infrastructure is central to reducing energy consumption. Optimization is fundamental to any approach to climate change mitigation. While optimization technology has been on offer for almost 70 years, most applications of optimization technology have been in piecemeal, monolithic optimization systems. Yet the climate change crisis requires optimization on a large-scale, and in manner that permits entities in a massive planetary supply chain to collaborate to achieve the commonly agreed upon carbon mitigation objective. Traditional stand-alone "batch" optimization will also not be adequate for this setting, but will need to be tightly coupled with networks of planners and controllers. This chapter presents a vision for the Optimizing Web – a large global network of interoperating optimizers that is as ubiquitous as the present-day web, and that leverages it's existing infrastructure for green ICT.

INTRODUCTION

There is widespread recognition of the climate change crisis, and the need to develop scientific, technological and managerial responses. Current thinking on climate change responses emphasizes the development of alternative energy sources, the development of smart automotive technology and the introduction of macro-economic levers (e.g., carbon taxes, ETS's) to alter energy consumption behaviour at the level of both enterprises and individuals.

Fundamental to any solution to the problem is *optimization* – in particular, the ability to optimize energy use – yet this has been largely ignored in the current discourse. It is well-known that our global industrial/technological infrastructure, including transportation systems, manufacturing plants,

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human habitat and so on, is typically operated in an ad-hoc and significantly sub-optimal fashion. This remains the case despite our having had access to sophisticated optimization technology for almost the past seven decades (present day operations research techniques trace their roots to the pioneering work of George Dantzig in the early 1940s that resulted in the original optimization algorithm – linear programming). Much could be achieved by ensuring more widespread adoption of optimization technology.

Optimizations problems are typically defined in terms of a set of *decision variables* (an assignment of a value to each of these constitutes a solution to the problem), a set of *constraints* (which specify allowed combinations of values for these variables) and an *objective function* defined on the set of decision variables. Solving an optimization problem involves seeking to *maximize* or *minimize* the value of this function, i.e., to find an allocation of values to the decision variables such that the value of this function is either maximized or minimized.

The opportunities for optimizing energy use extend far beyond those presented by simply facilitating greater uptake of optimization solutions. We know that composing an optimal solution to a problem involving the set of decision variables $\{X, Y\}$ with the optimal solution for a problem involving the variables $\{Y, Z\}$ does not necessarily provide an optimal solution to the problem obtained by combining these two smaller problems (assuming the existence of a common objective function). This is often because constraints that hold between sub-problems are not visible when one limits one's view to a specific sub-problem. Thus, locally optimal behaviour does not guarantee "globally" optimal behaviour. Conversely, an optimal solution for a problem might not necessarily be optimal for each of its constituent sub-problems.

While optimization technology has been on offer for almost 70 years, most applications of optimization technology have been in piecemeal, monolithic optimization systems. Yet the climate change crisis requires optimization on a large-scale, and in manner that permits entities in a massive planetary supply chain to collaborate to achieve the commonly agreed upon carbon mitigation objective. Traditional stand-alone "batch" optimization will also not be adequate for this setting, but will need to be tightly coupled with networks of planners and controllers. Agent technology offers the best starting point for developing such technology.

The climate change crisis has presented the optimization community with a historic opportunity – for the first time ever, we have a globally agreed-upon objective function, the carbon footprint minimization objective. This opens up the possibility for large-scale *collaborative optimization*, where large numbers of autonomous entities might collaborate to obtain an optimal value for a shared objective function. Our aim to design and validate the conceptual underpinnings of the *optimizing web* – the infrastructure that would support very large scale collaborative optimization across a potentially global collection of local optimizers. The vision is to provide ubiquitous collaborative optimization services, at the level of individual devices, vehicles within transportation systems, units within organizations or plants as well aggregations of all of these. The optimizing web would provide a protocol (or protocols) for local optimizers to inter-operate to optimize the global carbon footprint minimization objective, while making appropriate trade-offs in relation to their local objectives. While the modelling and solution of "local" optimization has been the focus of attention for the operations research (OR) community for several decades, this project addresses the question of how large collections of optimization solutions, with possibly intersecting signatures (sets of common variables), might be made to inter-operate to optimize a shared function (the carbon footprint minimization objective).

This poses several interesting challenges. The first of these is defining and detecting objective