Challenges for Constraint Reasoning and Optimization in Computational Sustainability

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Abstract. Computational Sustainability is a new emerging research field with the overall goal of studying and providing solutions to computational problems for balancing environmental, economic, and societal needs for a sustainable future. I will provide examples of challenge problems in Computational Sustainability, ranging from wildlife preservation and biodiversity, to balancing socio-economic needs and the environment, to large-scale deployment and management of renewable energy sources, highlighting overarching computational themes in constraint reasoning and optimization and interactions with machine learning, and dynamical systems. I will also discuss the need for a new approach to study such challenging problems in which computational problems are viewed as "natural" phenomena, amenable to a scientific methodology in which principled experimentation, to explore problem parameter spaces and hidden problem structure, plays as prominent a role as formal analysis.

Extended Abstract

Humanity's use of Earth's resources is threatening our planet and the livelihood of future generations. The dramatic growth in our use of natural resources over the past century is reaching alarming levels. Our Common Future [3], the seminal report of the United Nations World Commission on Environment and Development, published in 1987, raised environmental concerns and introduced the notion of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their needs." Our Common Future also stated the urgency of policies for sustainable development. The United Nations Environment Program in its fourth Global Environmental Outlook report published in October of 2007 [4] and the United Nations Intergovernmental Panel on Climate Change (IPCC) [2] reiterated the concerns raised in Our Common Future. For example, the fourth Global Environmental Outlook report stated that "there are no major issues raised in Our Common Future for which the foreseeable trends are favorable" [4].

Key sustainability issues translate into decision making and policy making problems concerning the management of our natural resources involving significant computational challenges that fall into the realm of computing and information science and related discilines, even though in general they are not studied

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by researchers in those disciplines. In fact, the impact of modern information technology has been highly uneven, mainly benefiting large firms in profitable sectors, with little or no benefit in terms of the environment. It is therefore imperative and urgent that we turn our attention to computational problems that arise in the context of the environment and the way we use our natural resources.

Our vision is that computer scientists can — and should — play a key role in increasing the efficiency and effectiveness of the way we manage and allocate our natural resources. Furthermore, we argue for the establishment of critical mass in the new emerging field of *Computational Sustainability.* Computational Sustainability is an interdisciplinary field that aims to apply techniques from computer science and related fields, namely information science, operations research, applied mathematics, and statistics, to balance environmental, economic, and societal needs for sustainable development. The range of problems that fall under Computational Sustainability is rather wide, encompassing computational challenges in disciplines as diverse as ecology, natural resources, atmospheric science, and biological and environmental engineering. Research in Computational Sustainability is therefore necessarily an interdisciplinary endeavor, where scientists with complementary skills must work together in a collaborative process. The focus of Computational Sustainability is on developing computational and mathematical models, methods, and tools for decision making concerning the management and allocation of resources for sustainable development.

In this talk I will provide examples of computational sustainability challenge domains ranging from wildlife preservation and biodiversity, to balancing socio-economic needs and the environment, to large-scale deployment and management of renewable energy sources. I will discuss how computational sustainability problems offer challenges but also opportunities for the advancement of the state of the art of computing and information science and related fields, highlighting some overarching computational themes in constraint reasoning and optimization, machine learning, and dynamical systems. I will also discuss the need for a new approach to study such challenging problems in which computational problems are viewed as “natural” phenomena, amenable to a scientific methodology in which principled experimentation, to explore problem parameter spaces and hidden problem structure, plays as prominent a role as formal analysis [1]. Such an approach differs from the traditional computer science approach, based on abstract mathematical models, mainly driven by worst-case analyses. While formulations of real-world computational tasks lead frequently to worst-case intractable problems, often such real world tasks contain hidden structure enabling scalable methods. It is therefore important to develop new approaches to identify and exploit real-world structure, combining principled experimentation with mathematical modeling, that will lead to scalable and practically effective solutions.

In summary, the new field of Computational Sustainability brings together computer scientists, operation researchers, applied mathematicians, biologists, environmental scientists, and economists, to join forces to study and provide solutions to computational problems concerning sustainable development, offering challenges but also opportunities for the advancement of the state of the art of computing and information science and related fields.

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