COMPUTATIONAL MODELS FOR SUSTAINABLE DEVELOPMENT

*Monendra Grover, Rajesh Kumar, Tapan Kumar Mondal and S. Rajkumar

* Author for correspondence
email:monendra_grover@yahoo.com
National Bureau of Plant Genetic Resources, Pusa, New Delhi -110012. India.

Abstract: Genetic erosion is a serious problem and computational models have been developed to prevent it. The computational modeling in this field not only includes (terrestrial) reserve design, but also decision modeling for related problems such as habitat restoration, marine reserve design, and nonreserve approaches to conservation management. Models have been formulated for evaluating tradeoffs between socioeconomic, biophysical, and spatial criteria in establishing marine reserves. The percolation theory and shortest path modeling have also been used. In this article we discuss the computational models that have been developed keeping in mind the sustainable developmentConservationists estimate that alarming rate at which biological species are disappearing will have an indelible impact on humanity. Targets which were set in 2002 to reduce the biodiversity loss by 2010 have not been met. The third global diversity outlook report said that loss of wildlife and habitats could not only exacerbate climate change through rising emissions but could also have a negative impact on food sources and industry.

Computational Models in Aid Of Developing Policies For Sustainable Development

The development of right policies for sustainable development is very important and involves complex decision making about the judicious use of natural resources and about striking a balance between societal, economic and environmental needs. Computational models have been used for policy formulation for example, the impact project (http://www.policy-impact.eu/home, impact: integrated method**s** for policy making using argument modeling and computer assisted text analysis**)** aims to make progress in the area of state-of the art of computational models of argumentation about policy issues, contribute to computational linguistics by developing methods for mining arguments in natural language texts, find ways and means to increase the quantity and quality of public participation in consultation processes, and invent user friendly tools (such as graphic interfaces to increase public participation). These tools can also be used for policy formulation on Biodiversity. This will lead to involvement of more people, and key stakeholders to integrate biodiversity considerations into their work.

The IMPACT argumentation toolbox aimed to consist of, firstly, an argument reconstruction tool: the manual reconstruction of arguments from natural language texts was done which was supported by a library of argumentation as a constituent of argument reconstruction tool. This was done in order to enable future web logs to mark up the structure of arguments in articles in a way which allows arguments to be automatically aggregated, analyzed and visualized. The legal knowledge extension format formed a part of the basis of this tool.

A policy modeling and analysis tool based on the computational models of argumentation about alternative courses of action depending on the goals and values of multiple stakeholders was also included. Prior research on knowledge representation languages for concepts (ontologies), defeasible generalizations (rules) and precedent cases including the legal knowledge interchange format (lkif) was utilized for this. The lkif was developed in the Estrella project (http://www.estrellaproject.org, Estrella:The European project for Standardized Transparent Representations in order to Extend Legal Accessibility IST-2004-027655) aimed to develop and validate an “open, standards-based platform allowing public administrations to both develop and deploy comprehensive legal knowledge management solutions”. Legal document and data management, in addition to knowledge based systems is supported by Estrella, to provide a holistic solution for improving the efficiency and quality of public administration which requires the application of complex legislation and other legal sources. Both the legal and legislative data and its analysis including possible implications on past, present and future scenarios will have to be incorporated to arrive at informed and efficient solutions. The public administration and other users are provided with a variety of competing development environments, inference engines and other tools to choose from. The main technical objectives of the Estrella project are to “develop a Legal Knowledge Interchange Format (LKIF), building upon emerging XML-based standards of the Semantic Web, including RDF and OWL, and Application Programmer Interfaces (APIs) for interacting with legal knowledge-based systems”. The policy modeling and analysis tool is proposed to include a graphical user interface for a dialogue with an inference engine to simulate and analyze the consequences of a proposed policy. The tool has been proposed to be rich in graphical interfaces to enable clear visualization of its reasoning. The comparative analysis of different policy proposals will also be facilitated by this tool**.**

A structured consultation tool, based on prior research on the PARMENIDES system was a part of the toolbox. The PARMENIDES system was developed by University of Liverpool (http://cgi.csc.liv.ac.uk/~parmenides/index.php). The Parmenides system is a system for deliberative democracy and allows the government and public to interact in a two way fashion. It enables the government to present policy proposals to the public and lets the public submit their views on the policy. Parmenides exploits argumentation schemes and argumentation frameworks to graphically analyze the opinions submitted by the users. The structured consultation tool is an intelligent, advanced, polling and survey tool, based on the computational models of argumentation. The models of argumentation schemes together with the model of the issues and the arguments put forward previously in the ongoing consultation are used to generate questions in the surveys. The tool substantively increases the signal to noise ratio in online discussions, without restricting the solid arguments which can be made, by helping users to apply a model of rational argument. The arguments can be more easily tracked, mapped and visualized, since there is no need to manually reconstruct arguments from natural language texts.

An argument analysis, tracking and visualization tool, based on computational models of argument and argument mapping methods is also a constituent of IMPACT argumentation toolbox. There are three main features of this tool. The analysis features of this tool enables citizens to identify the applied argumentation schemes, to list implicit premises helpful for asking questions. The tracking features of this tool enables users to register their interest in particular issues and request as well as receive notification whenever new arguments have been put forward which affect these interests. The visualization feature of this tool provides a variety of graphical and interactive views onto argument graphs. This will enable citizens to appreciate and analyze the complexity of the policy issues in their entirety and contribute to the policy formulation. Besides the policy formulation tools several other issues in sustainability have been addressed by using computational models as detailed below.

Computational Sustainability

Computational Sustainability is a highly interdisciplinary field, with the vision that information and computing science have a potential to play an indispensable role in increasing the efficiency and effectiveness of management and allocation of our natural resources. Some of the examples of studying computational biodiversity include more efficient use of natural resources, more realistic models of maintaining and increasing biodiversity and more effective large scale computational equilibrium models of renewable energy. Computational sustainability has a unique societal relevance and effective environmental component.

Computational thinking and approach is essential to provide effective and efficient solutions which include balancing environmental, economic and societal needs. Computational sustainability takes a holistic approach and encompasses problems in diverse disciplines such as ecology, natural resources, atmospheric science, materials science, renewable energy and biological and environment engineering. Computational sustainability addresses the sustainability issues by translating them into decision and optimization problem.

The field of computational sustainability not only draws from computer science and mathematics, it has pushed the boundaries of these disciplines itself. This is in view of the fact that sustainability issues are of unique scale complexity and impact. The sustainability problems require integration of a wide variety of techniques from various areas with in applied mathematics and computer science such as data mining, machine learning, optimization, constraint processing and dynamical systems. The field of complex systems is also relevant to computational sustainability. The systems studied in the realm of computational sustainability consist of highly interconnected components or agents, often with conflicting interests.

The Institute of computational sustainability is one of the leading institutes in the world for computational sustainability (http://www.cis.cornell.edu/ics/). The multi-disciplinary, multi-institutional ICS research team is based at Cornell University of and includes leading computer and environmental scientists at Oregon State University, Bowdoin College, Howard University, and The Conservation Fund (TCF).

The computational sustainability has had a direct impact on the sustainability research for example. The ICA has developed methods and models to design economically viable conservation corridors for grizly bears and other species in U.S. and understand the impact of climate change in terms of aerosol interactions, desert dust, and paleodata based model estimates. Fundamental contributions to the mathematics and computer science have also been made such as deriving new insights into dynamical systems, specifically in the areas of parameter estimation, quantifying uncertainty, and synchronization, and developing large scale computing paradigms for massively large data sets and simulation-intensive studies. Besides this it has been shown that Markov Random Field theory used in combination with Message Passing algorithms constitutes a powerful theoretical framework for the development of algorithms for information distribution and fusion.

Biodiversity and Species Conservation

The habitats must be protected by creating biologically valuable sites or reserves, thereby improving the chances of species survival. Since the resources available for conservation are limited these sites/reserves must be carefully chosen. The site selection or reserve design problem includes optimization of various criteria such as habitat suitability for species and simultaneously satisfying constraints such as limited budgets [Ando *et. al.* (1998), Moilanen *et. al.* (2009), Polasky *et. al*. (2008)].

In recent years the concept of conservation corridors has been proposed. These corridors are continuous areas of protected land that link biologically significant zones. The design of conservation corridors is a special aspect of the site-selection problem. The objective of creating conservation corridors is to create connected corridors made up of parcels of land that have the potential to yield the highest possible level of environmental benefit ("utility") [Onal *et. al.* (2005), Williams *et. al.* (2005)]. This problem can be mathematically and computationally formulated and analyzed. In fact the problem of creating a conservation corridor for grizzly bears in the U.S. northern Rockies was formulated mathematically as a so-called "connection sub-graph problem" [Conrad *et. al.* (2007), Dilkina *et. al.* (2009), Gomes *et. al.* (2008)]. This problem was computationally intensive and placed significant demands on computational methods. To have a deeper understanding of the underlying structure of the problem a budget-constrained, utility-optimization approach using hybrid constraint-based mixed-integer programming that exploits problem structure was developed by the above mentioned authors.

Complexity in site selection and corridor problems increase when a variety of economic and biological variables are taken into account. Economic variables such as purchase, conservation easements, auctions, and biological variables such as dynamic and stochastic environments, and multiple species must be considered.

Large scale sensor networks are becoming important in environmental monitoring [Raghavendra *et. al.* (2009), Werner-Allen *et. al.* (2006)]. These networks aid in collection of biological, ecological and climatic data. The data collected from these networks is huge and presents many challenges. Besides this designing a large-scale sensor network also presents many computational challenges such as network architecture, operating system, and programming environments [Akyildiz *et. al.* (2007)]. For example**,** the selecting the optimal place of sensors to maximize information gain, and minimizing the communication problems is a computationally challenging task [Krause *et. al.* (2009)].

Nature provides a diverse array of benefits to people. The importance of incorporating these "ecosystem services" into resource management decisions is increasingly being felt. However quantifying the levels and values of these services has not proved to be easy. A spatially explicit modeling tool, Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST), to predict changes in ecosystem services, biodiversity conservation, and commodity production levels has been developed. This tool InVEST has been applied to stakeholder-defined scenarios of land-use/land-cover change in the Willamette Basin, Oregon [Nelson *et. al.* (2009)]. It was found that scenarios that received high scores for a variety of ecosystem services also had high scores for biodiversity. Scenarios involving more development had higher commodity production values, but lower levels of biodiversity conservation and ecosystem services. However, including payments for carbon sequestration alleviates this trade off.

Socioeconomic and Environmental Needs in sustainability

Complex socio-economic interrelationships are important determinants of sustainability. For example, pastoral systems in East Africa that involve herds of cattle, camels, sheep and goats have been studied. Barrett et al. [Barrett *et. al.* (2007)] have highlighted the complex socio-economic interrelationship between poverty, food, security and environmental stress, and further emphasized on links between resource dynamics and poverty-trap in small-holder agrarian systems. Gomes and co-workers [(Gomes, 2009)] have used machine-learning methods to determine the parameters of the model and also its structure, based on complex data about, climate patterns, natural resources and households.

These models will be very useful in policy formulation. Policy makers can hope to predict the effects of potential policy interventions and environmental challenges using these models. These models will also be helpful in descriptive studies

The automated decision-support tools, for providing humanitarian aid in response to natural calamities is also included in computational sustainability topics. The design of such systems will require user friendly graphical interfaces to be used by aid workers

Energy-Efficient Data Centers and need for Green Computing

For the last two hundred years a carbon-intensive growth path has actively enabled industrialization and economic growth across the world [Nilekani (2007)]. Now is the time to design alternative intelligent or smart control systems for energy efficient building, vehicles and appliances.

Intensive use of IT has had some pitfalls. Data centers (i.e., computing facilities with electronic equipment for data processing, storage, and communications networking) particularly use the e**nergy** inefficiently. Use of toxic metals and high levels of heat (carbon) emission from IT equipment necessitates the alternative low heat emitting , recycled computers. The concept of green computing has come to prominence in recent years in view of the above. In the article Harnessing Green IT: Principles and Practices, San Murugesan defines the field of green computing as "the study and practice of designing, manufacturing, using, and disposing of computers, servers, and associated subsystems—such as monitors, printers, storage devices, and networking and communications systems—efficiently and effectively with minimal or no impact on the environment [Murugesan (2008)]." Data centres, besides using the energy inefficiently also produce carbon dioxide on a significant scale. Thus the IT industry not only has to look at dense server configurations and advanced power management hardware to reduce energy consumption, they also have to focus on smart cooling systems and virtualization tools [Katz (2009)]. The large amounts of data provided by large-scale sensor networks [Bodik *et. al.* (2008), Hoke *et. al.* (2006), Patnaik S R Marwah *et. al.* (2009) and Shah *et. al.* (2008)] is the basis of these new approaches.

For developing countries it is essential to figure out a coherent pricing mechanism around the various sources and sinks for carbon. “One of the challenges for any kind of environmental pricing is deciding how we should include the communities in India (and other developing countries) that live on our common land and use these resources [Nilekani (2007]. Large scale informal systems make mechanisms such as carbon pricing highly complex. Computational models can go a long way in developing efficient carbon pricing policies.

The Smart Grid

The Concept of Smart Grid was proposed to modernize the electricity grids**.** A smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system. Operation and planning of such complex digital ecosystems will not only require technological advances in sensing and measuring technologies, advanced control methods but also advances in computing and information science related to computational aspects of game-theory models and mechanism design, multi agent based models, decision-support and optimization tools and security and privacy tools. Some of these advances are already underway. In recent years lot of emphasis has been laid on the renewable energy sources, such as biofuels and biomass, geothermal, solar, and wind power.

Renewable energy

The logistics and planning of the large-scale biofuels production system emerge as complex sto-chastic optimization problems that must take into consideration feedstock and demand and the dynamics of demand and capacity [Hosten *et. al.* (2004)]. A more ambitious project will be the development of computational models that show interactions between different energy sources and the agents (e.g., households, landowners, farmers, ethanol producers, gasoline refiners, food producers) and impacts on the environment (e.g., greenhouse gas emissions, water, soil erosion, biodiversity, etc.)

The challenge is to develop realistic models that capture multiple impacts and interdependencies imposing least number of unrealistic assumptions. In traditional approaches, convexity assumptions force unique equilibria, or at the very least, the set of equilibria are themselves convex [Codenotti *et. al.* (2005), Heijungs *et. al.* (2002) and Ye Y (2008)]. This has made their algorithmic solution possible, but such models do not capture key aspects of systems. Researchers will have to develop more complex decision models through collaboration with resource economists, environmental scientists, and computer scientists.

The algorithmic solution to the problems formulated in traditional models have been possible because convexity assumptions force unique equilibria, or at the very least, the set of equilibria are themselves convex [Codenotti *et. al.* (2005), Heijungs *et. al.* (2002) and Ye Y (2008)]. However these models must employ a more comprehensive systems approach and researchers will have to involve computer scientists, environmental engineers and resource economists

An important issue in environmental policy is balancing individual interests and the common good [Hardin (1968)]. In this area, game-theory models can model the interactions of multiple agents and show the contribution of competing interests. In general, to capture the structure and properties of complex real-world sustainability problems and to provide meaningful solutions, systematic and informed experimentation is as important as formal models and analysis [Gomes *et. al.* (2005) and Gomes *et. al.* (2007)].

Conclusions

Keeping in view the vast array of disciplines which have to be considered for developing sustainability measures and the rich data which these disciplines generate, it is imperative that sophisticated computational models are developed to describe the problem of sustainability, analyze it and come to meaningful conclusions. Involvement of all the stakeholders in these issues is necessary which has also been enhanced by computational models. Computational models are indispensable to organize the information, to aid in its analysis and come up with a proper action plan in sustainability studies.

References

[1] Akyildiz I F , Melodia T and Chowdhury K R *Int J Com Telecom Net* 51(2007) 921

[2] Ando A, Camm J, Polasky S and Solow A *Sci* **279**(1998) 2126

[3] Barrett C, Little P and Carter M (Eds) *Understanding and Reducing Persistent Poverty in Africa*. Florence, Ky.: (2007) Routledge.

[4] Bodik B , Armbrust M P , Canini K, Fox A, Jordan M and Patterson D A A Case for Adaptive Datacenters to Conserve Energy and Improve Reliability. Technical Report No. UCB/EECS-2008-127. Berkeley, Calif.: EECS Department, University of California, (2008) Berkeley.

[5] Codenotti B, Pemmaraju S and Varadarajan K On the polynomial time computation of equilibria for certain exchange economies. In Proceedings of the 16th ACM-SIAM Symposium on Discrete Algorithms. Philadelphia: (2005) SIAM pp72–81

[6] Conrad J C , Gomes W J, van Hoeve A , Sabharwal A and Suter J Connections in Networks: Hardness of Feasibility versus Optimality. pp. 16–28 in Proceedings of the Fourth International Conference on the Integration of AI and OR Techniques Constraint Programming, Brussels, Belgium. Berlin, Heidelberg: Springer-Verlag. (2007)

[7] Dilkina B and Gomes C Wildlife Corridor Design: Connections to Computer Science. pp**.** 3–4 in Proceedings of the Workshop on Constraint Reasoning and Optimization for Computational Sustainability (CROCS-09). (2009) Lisbon: CP-09.

[8] Gomes C , van Hoeve W J and Sabharwal A Connection in Networks: A Hybrid Approach. Pp. 303–307 in Proceedings of the Fifth International Conference on the Integration of AI and OR Techniques Constraint Programming, Paris, France. Berlin, Heidelberg: Springer Verlag. (2008)

[9] Gomes C and Selman B *Nat* **435**(2005) 751

[10] *Gomes C and Selman B Const Prog Lett* **1**(2007)15

[11] Hardin G *Sci* **162**(1968)1243

[12] Heijungs R, Suh S (Eds) The Computational Structure of Life Cycle Assessment (Eco-Efficiency in Industry and Science). Boston: Kluwer Academic Publishers. (2002)

[13] Hoke E, Sun J and Faloutsos C. InteMon: Intelligent System Monitoring on Large Clusters. pp 1239–1242 in Proceeding of Very Large Databases (VLDB'06). Available online at http://www.vldb.org/conf/2006/p1239-hoke.pdf(2006)

[14] Hosten S, Lee J and Thomas R (Eds). AMS Proceedings of Symposia in Applied Mathematics, Providence, R.I.: American Mathematical Society (2004) 85

[15] Katz R H Tech Titans Building Boom. IEEE Spectrum Online. Available online at *http://www.spectrum.ieee.org/feb09/7327*. (2009)

[16] Krause A and Guestrin C *Comp Mag* **42**(2009) 38

[17] Moilanen A , Wilson K and Possingham H (Eds) Spatial Conservation Prioritization. New York: Oxford University Press. (2009)

[18] Murugesan S *IEEE IT Professional*, (2008) pp 24

[19] Nelson E , Mendoza G , Regetz J, Polasky S, Tallis H , Cameron D, Chan K MA , Daily G, Goldstein J, Kareiva P, Lonsdorf E, Naidoo R , Ricketts T, Shaw M. *Front Ecol Envir* **7**(2009)4

[20] Nilekani N Imagining India. Penguin Books (2007)

[21] Onal H and Briers R . *Env Mod Asses* **10**(2005)193

[22] Patnaik P, Marwah S R and Ramakrishnan N In Proceedings of Knowledge Discovery and Data Mining (KDD'09), June 28–July 1, (2009), Paris. France. New York: Association for Computing Machinery.
[23] Polasky S , Nelson E , Camm J , Csuti B , Fackler P , Lonsdorf E , Montgomery C , White D, Arthur J, Garberyonts B , Haight R , Kagan J , Starfield A, and Tobalske C *Biol Conser* **141**(2008)1505
[24] Raghavendra C S . Sivalingam K M , and Znati T (Eds) Analysis of Wireless Sensor Networks for Habitat Monitoring. Springer Netherlands. (2009) 399–424
[25] Shah A , Carey V , Bash C and Patel C. Energy analysis of data center thermal management systems. *J Heat Transf* **130**(2008) 21401
[26] Werner-Allen G, Lorincz K, Welsh M, Marcillo O, Johnson J , Ruiz M and Lees J *IEEE Internet Comp* **10**(2006)17
[27] Williams J C , ReVelle C S and Levin S *Env Mod Asses* **10**(2005)163
[28] Ye Y *Math Prog* **111**(2008)315