**An open-source and generic optimiser for Geonamica-based Decision Support Systems**

In this appendix, an open-source software package that enables the use of multiobjective genetic algorithms with Geonamica-based decision support systems is described. Geonamica-based decision support systems are an integrated assessment model comprised of a set of interlinked (i.e. coupled) modelling components, which is made available to users either through a command-line model-runner, or through a graphical user interface that is tailored to the decision-making processes and decision-options available for a particular decision-making context. On the other hand, multiobjective genetic algorithms are an optimisation routine that identify values of decision variables that exhibit Pareto-optimal tradeoffs across decision criteria. Genetic algorithms are a robust optimiser for difficult optimisation problems, including those with nonlinearity (including multimodality) in objective space and saliency in decision variable space. When used in conjunction, Geonamica-based integrated assessment models and genetic algorithms implement a simulation-optimisation approach, and have applicability to a wide range of environmental and natural resource management problems. In particular, the use of optimisation aids the use of model-based decision support systems by helping to provide focus on well-performing decision variable values (i.e. the best sets of management options) when used for making management plans. It is also of note that the use of optimisation and the presented software have utility for the calibration — and specifically, the parameterisation — of integrated assessment models (Newland et al., 2018).

The genetic algorithm chosen for implementation within this optimisation package is an adapted implementation of the non-dominated sorting genetic algorithm, first introduced by Deb et al (Deb, 2002). This genetic algorithm uses an elitist and multi objective strategy and is regarded as an industry standard with a proven track-record in application to environmental and natural resource management problems and model calibration. A significant challenge in the application of simulation-optimisation approaches with integrated assessment models is the typically long runtimes of such models, and the software introduced overcomes this difficulty through parallelisation of the search. The software is able to run on Windows, Linux or Macintosh desktop computers or on high-performance computing clusters. As Geonamica-based DSSs are Windows specific applications, the use of the optimisation on non-Windows systems has been tested for some applications using the Wine emulator.

The coupling between the optimisation and Geonamica is achieved primarily through the XML-based model specification that Geonamica is built upon. Therefore, the optimisation packages described here are also relevant for any model in which decision variables can be specified through an XML interface.

**A.1 Software and data availability**

The software implementing the optimisation has two parts. First, there is a backend optimisation package, which implements the non-dominated genetic algorithm (NSGAII), called ‘Parallel NSGA-II Backend’. Second, there is a frontend that includes a graphical user interface, in which an optimisation problem can be specified with reference to a Geonamica-based integrated assessment model; this front end solves the optimisation problem through compiling with and running the ‘Parallel NSGA-II Backend’.

Name of tool: Parallel NSGA-II Backend

Developers: Jeffrey Newman

Hardware required: Hardware requirements are case study dependent and largely depends on the requirements of the simulation model (i.e. the Geonamica-based IAM) that is used to quantify the optimisation problem’s objectives and constraints

Software required: Software dependencies include the Boost C++ libraries, which are a free, open-sourced, mature and peer reviewed collection of C++ code that implements a number of commonly used programming data types and routines.

Programming languages: Standard C++; compiles under the cross-platform and open source gnu and clang compiler chains, as well as Microsoft’s Visual C++.

Program size: approx. 50mb (makes extensive use of inline functions which creates faster executables at the expense of program size).

Availability and cost: Free open sourced code licensed under the GNU General Public License v2.0. Project is hosted on GitHub at <https://github.com/jeffrey-newman/parallel-nsgaII-backend>.

Year first available: 2016

Name of tool: Geonamica-Optimisation

Developers: Jeffrey Newman

Hardware required: Hardware requirements are case study dependent and largely depends on the requirements of the Geonamica IAM that is is used to quantify the optimisation problem’s objectives and constraints.

Software required: Software dependencies include the Boost, GDAL, pugixml and OpenCV C++ libraries, which are free, open-sourced, and mature C++ codes. The software is also built upon a folked version of Alex Hagen-Zanker’s open-source raster input/output library (‘Pronto|raster’).

Programming languages: Standard C++; compilable under the cross-platform and open source gnu and clang compiler chains, as well as Microsoft’s visual C++.

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Availability and cost: Free open sourced code licensed under the GNU General Public License v3.0. Project is hosted on GitHub at <https://github.com/jeffrey-newman/Geonamica-Optimisation>.

Year first available: 2016