

Borg-RW version 1.0

User Guide

Center for Advanced Decision Support for Water and Environmental Systems (CADSWES)

1. Introduction

The **Borg** Multi-objective Evolutionary Algorithm (MOEA) is an optimization algorithm developed by David Hadka and Patrick Reed at the Pennsylvania State University. **Borg-RW** is an application written by CADSWES staff which uses the Borg library and RiverWare to solve optimization problems.

The Borg-RW optimization framework involves the following elements:

- **RiverWare model:** a working RiverWare model, including policies, a batch (RCL) script, and input and output DMIs.
- **Decision variables** (aka levers): a set of scalar quantities in the model, each of which corresponds to a single series, scalar, or table slot value in the RiverWare model. Included in the description of each decision variable is the range of value of interest for that quantity. Decision variable values provided by Borg are linearly transformed and rounded before being passed to RiverWare.
- **Objectives:** the output quantities to be optimized, each of which corresponds to a single series or scalar slot value in the model.
- **Constraints:** a set of constraints on individual modeled quantities, each of which has the form:
 <quantity> <comparison operator> <threshold>
 where the constrained quantity is a single series or scalar slot value in the model, and the comparison operator is one of \leq , \geq , or $=$. The satisfaction value of a constraint given the value x for the constrained quantity is defined as 0.0 if the constraint is satisfied, otherwise:
 $\text{satisfaction} = -1 * \text{scale} * |\text{threshold} - x|$
- **Metric:** scalar output quantities of interest that are not included in the optimization.

Borg-RW uses the Borg library to explore how various combinations of decision variable values affect objective values. This process involves the following steps:

1. Read the configuration files which describe the optimization problem including the locations of the RiverWare model as well as descriptions of the variables, objectives, constraints, and metrics.
2. Until the termination criteria is reached, repeatedly execute a step of the Borg algorithm. Each step involves one or more function evaluations. In the context of Borg-RW, a function evaluation is an execution of the RiverWare model that is driven by a specific set of decision variable values provided by Borg. For each function evaluation, Borg-RW takes the following actions:
 - a. Acquire the next set of decision variable values from the Borg library.
 - b. Transform these values as appropriate (typically each value is linearly transformed into the valid range for the destination RiverWare slot, then rounded to discretize the values being considered).
 - c. Write the transformed values to the appropriate DMI input files.

- d. Execute RiverWare in batch mode. The RiverWare execution is controlled by the batch RCL script, and begins by executing a control file input DMI to read the transformed decision variable values for the run into the model, then an MRM run is initiated. During this run a per-trace output DMI writes the objective, constrained quantity, and metric values to files, renaming the data files to include the trace number (so subsequent traces won't overwrite them).
- e. Read the objective, constrained quantity, and metric values.
- f. For each objective, aggregate the per-trace values (e.g., compute the average or maximal value).
- g. For each constraint, compute an aggregate satisfaction value.
- h. For each metric, aggregate the per-trace values.
- i. Provide the aggregate objective and constraint satisfaction values to the Borg library.
- j. Write objective, constraint satisfaction, and metric values to output files.

2. Output

Borg-RW writes diagnostic messages to the console (standard output) as the algorithm progresses, as well as writing the following files:

- **VariablesValues.Borg.txt:** The original decision variable values from Borg, one row per iteration.
- **AllValues.txt:** Variable, aggregate objective, aggregate constraint satisfaction, and metric values, one row per function evaluation. The variable values are transformed.
- **Runtime.txt:** Progress information written at each step of the Borg algorithm. The information for a given step includes the row of values written to AllValues.txt for the most recent function evaluation (i.e., variable, objective, constraint satisfaction, and metric values).
- **Runtime.Parsable.txt:** the same information as Runtime.txt, written in a format that can more easily be parsed by a machine.
- **Archive.txt:** variable, objective, and constraint satisfaction values for the most recently completed step of the Borg algorithm. The variable values are transformed.
- **Archive.Borg.txt:** variable, objective, and constraint satisfaction values for the most recently completed step of the Borg algorithm. The variable values are not transformed (i.e., they are the original decision variable values from Borg).

3. File-driven Run

As described above, in a standard Borg-RW execution the Borg library is used to optimize a RiverWare model with respect to multiple objectives. Borg-RW also supports the “file-driven run” execution mode in which Borg-RW evaluates a set of decision variable vectors that are read from in an input file (instead of being dynamically generated by the Borg library, as in a standard execution). The output consists of console diagnostics and the AllValues.txt file (the other output files generated by a standard Borg-RW execution do not apply in this context).

Note that for a file-driven run, the input file can be an Archive.Borg.txt or VariableValues.Borg.txt from a previous run. This allows one to re-create one or more RiverWare runs from a previous execution of Borg-RW, or one can modify the batch run script or model file to explore a different scenario with inputs from previous runs.

4. Installation

Borg-RW is a stand-alone Windows application which is installed by saving the executable (borg-rw.exe) to an appropriately accessible location on your file system.

5. Usage

Borg-RW is executed from a command line with one or more configuration file arguments:

```
Borg-rw.exe <configuration file> [<configuration file> ...]
```

If multiple configuration files are present, their order on the command line is not important.

6. Configuration

The behavior of Borg-RW is controlled by a set of configuration files. This section provides an informal description of the XML format of these configuration files, organized by XML element.

- **borgRwConfig**: the top-level configuration element
 - **rwExec**: the path of the RiverWare executable.
 - **fileDrivenRun** (optional)
Required attribute **inputFile**: the path of the input file from which to read variable values with which to drive the Borg-RW execution.
 - **populationSize**: Integer. The Borg population size.
 - **maxEvaluations**: Integer. The maximum number of function evaluation (i.e., the termination criterion).
 - **rclScript**: the name of the batch RCL script.
 - **numTrace**: the number of runs conducted by the RiverWare execution.
 - **variableList**: description of the variables.
Required attribute **numVar**: the integer number of variables.
 - **variable**: specification for a single variable. If there is only one variable element in the variable list, it is assumed to apply to all variables.
 - **bounds**:
Required attribute **lower**: lower bound of the variable.
Required attribute **upper**: upper bound of the variable.
 - **objectiveList**
Required attribute **numObj**: the integer number of objectives.
 - **objective**: specification of a single objective.
 - **file**: DMI input file name.
 - **epsilon**: Borg epsilon for the objective.
 - **function**: Aggregation function, one of: "Identity", "Average", "Maximum", or "Median".
 - **constraintList**
Required attribute **numConstraints**: the integer number of constraints.
 - **constraint**: specification for a single constraint.
 - **file**: DMI input file name

- **comparisonOperator**: One of: "LessThanOrEqualTo", "EqualTo", or "GreaterThanOrEqualTo".
 - **threshold**: right-hand side value of the constraint.
 - **scaleFactor**: multiplicative scaling factor for computing satisfaction.
 - **aggregationMethod**: how to compute the cross-trace aggregate satisfaction value. One of: "SatisOfAveVal" (the satisfaction of the average constrained quantity's values), "MinSatisOfVals" (the minimum of the satisfaction values for the constrained quantity's values).
- **metricList**
Required attribute **numMetrics**: the integer number of metrics.
- **metric**: specification of a single metric.
 - **file**: DMI input file name
 - **aggregationFunction**: aggregation function, one of: "Average", "Minimum", or "Maximum".
- **columnList**
Required attribute **numCol**: the integer number of "columns".
- **column**: description for a single column. A column is associated with one or more decision variables and corresponds to a scalar quantity or a column of a table slot.
 - **file**: DMI input file name associated with the column
 - **numRow**: the number of rows in the column which correspond to decision variables.
 - **Limits**:
Required attribute **lower**:
Required attribute **upper**:
 - **Rows**:
Required attribute **first**: if not "Nan", a value to append as the first row of the DMI input file associated with this column.
Required attribute **last**: if not "Nan", a value to append as the next row after the decision variable values in the DMI input file associated with this column.
 - **Delta**: if -1, transform the column values into ascending values before writing them; if 1, transform them into descending values before writing them; otherwise, do not transform them.
 - **nanRows**: number of NaN rows to append to the file.
 - **roundingIncrement** (floating point): rounding increment. Decision variable values are rounded to the nearest multiple of this increment (midpoint values are rounded down).

7. Notes

- Borg-RW is designed to support MRM runs and assumes that the RiverWare output file name has the form:

<basefilename>.<trace number>.txt

Where the base file name is typically a RiverWare slot name. Thus for a single run model, the

output DMI executable would need to write files with “1” for the trace number component of the file name.

- The method for transforming a sequence of decision variable values provided by Borg into an ascending (or descending) sequence of table values within RiverWare assumes that the values coming from Borg are in the range [0, 1]. Borg-RW does not verify this assumption.