NAME

bcg_steady − steady-state numerical analysis of (extended) continuous-time Markov chains encoded in the BCG format

SYNOPSIS

bcg_steady [*bcg_options*] [**-epsilon** *eps*] [**-sol** *solution_file]* *[***-thr** *[***-append***]* *throughput_file]* *[***-mat** *matrix_file]* *[***-red** *reduced_matrix_file]* *[***-log** *log_file]* *filename***[.bcg]** [*parameter*=*value* ...]

where *bcg_options* is defined below (see GENERAL OPTIONS).

DESCRIPTION

bcg_steady performs steady-state analysis on *filename***.bcg**, which is an (extended) continuous-time Markov chain encoded in the BCG format.

bcg_steady first transforms *filename***.bcg** into a numerical matrix indexed by states. Then, it reduces this matrix by normalizing probabilistic transitions, removing unreachable states and "vanishing" states, keeping "tangible" states only (see section INPUT below for details about the BCG graphs accepted by **bcg_steady** and the definition of tangible and vanishing states). As a result, the reduced matrix obtained is the generator matrix of a continuous-time Markov chain. Finally, **bcg_steady** computes the corresponding equilibrium ("steady-state") probability distribution on the long run using the Gauss/Seidel algorithm (see e.g. [Ste94]). It can also compute throughputs for the transitions of the system.

GENERAL OPTIONS

The following *bcg_options* are currently supported: **-version**, **-create**, **-update**, **-remove**, **-cc**, and **-tmp**. See the **bcg**(LOCAL) manual page for a description of these options.

PARTICULAR OPTIONS

Taking as input *filename***.bcg**, on the form of which various restrictions apply (see section INPUT below), **bcg_steady** can produce five kinds of output files, depending on the command-line options specified.

The optional list of "*parameter*=*value*" arguments at the end of the command-line (where *parameter* is any character string that neither contain blanks nor the "=" character, and where *value* is any character string that does not contain blanks) is only meaningful to option **-thr**. These arguments have no influence on the actual numerical computations, they only serve to add columns in throughput tables (see section OUTPUT-2 below).

The following options are supported:

-epsilon *eps*

Set the precision of certain floating-point comparisons to *eps*, where *eps* is a real value. When *eps* is out of [0..1[, **bcg_steady** reports an error. Default value for *eps* is 1E-6.

-sol *solution_file*

Write the probability vector, computed at the equilibrium state, to file *solution_file* (see section OUTPUT-1 below for a description of the file format). If *solution_file* already exists, its contents will be overwritten. If *solution_file* is equal to the special string '-', the probability vector is displayed on the standard output. Not a default option.

-thr *[***-append***]* *throughput_file*

Write the transition throughputs, computed at the equilibrium state, to file *throughput_file*. The format of this file is determined by the suffix (i.e., file extension) of *throughput_file* (see section OUTPUT-2 below for a description of the available file formats). If *throughput_file* already exists, its contents will be overwritten, unless the **-append** option is specified, in which case the transition throughputs will be added at the end of *throughput_file* so as to form a proper data table. If the **-thr** option is missing or if *throughput_file* is equal to the special string '-', the transition throughputs are displayed on the standard output. Option "**-thr -**" is the default option when the command line does not contain any of the following options: **-mat**, **-red**, **-sol**, and **-thr**.

-mat *matrix_file*

Write the transposed "raw" matrix (prior to matrix reduction) to file *matrix_file*. The format of this file is determined by the suffix (i.e., file extension) of *matrix_file* (see section OUTPUT-3 below for a description of the available file formats). If *matrix_file* already exists, its contents will be overwritten. If *matrix_file* is equal to the special string '-', the matrix is displayed on the standard output. Not a default option.

-red *reduced_matrix_file*

Write the reduced transposed matrix to file *reduced_matrix_file*. The format of this file is determined by the suffix (i.e., file extension) of *reduced_matrix_file* (see section OUTPUT-3 below for a description of the available file formats). If *reduced_matrix_file* already exists, its contents will be overwritten. If *reduced_matrix_file* is equal to the special string '-', the matrix is displayed on the standard output. Not a default option.

-log *log_file*

Write various information about data structures and computations to file *log_file*. The format of this file is undocumented but self-understandable, and might change in future releases of *bcg_steady*. If *log_file* already exists, its contents will be overwritten. If *log_file* is equal to the special string '-', information is displayed on the standard output. Not a default option.

The files *solution_file*, *throughput_file*, *matrix_file*, *reduced_matrix_file*, and *log_file* should be pairwise different; otherwise, the result is undefined.

INPUT: THE BCG GRAPH

The input of **bcg_steady** is an extended Markovian model combining features from discrete-time and continuous-time Markov chains. In order to be accepted by **bcg_steady**, *filename***.bcg** must satisfy several conditions, otherwise an error message will occur.

All transition labels of *filename***.bcg** must have one of the following forms:

- "`rate` *%f*" (called a stochastic transition),
- "*label*`;` `rate` *%f*" (called a labelled stochastic transition),
- "`prob` *%p*" (called a probabilistic transition), or
- "*label*`;` `prob` *%p*" (called a labelled probabilistic transition),

where `%f` denotes a strictly positive floating-point number, `%p` denotes a floating-point number in the range]0..1], and *label* denotes a character string that does not contain the "`;`" character (*label* may be equal to the internal action, often noted "i" or "tau").

Note: transitions labelled with only "*label*" are always forbidden by **bcg_steady**, including the case where "*label*" denotes the internal action.

When constructing the "raw" matrix, all *label*s occurring in labelled probabilistic transitions are discarded.

If there exists a (labelled) probabilistic transition from a state *S1* to a state *S2*, then all (labelled) stochastic transitions from *S1* to any state (including *S2*) are discarded when constructing the "raw" matrix. This reflects that probabilistic transitions are instantaneous, while stochastic transitions are not.

We classify states as being either *vanishing* if at least one (possibly labelled) probabilistic transition goes out of these states, or *tangible* otherwise.

The input BCG graph should contain at least one tangible state, and it should not contain cycles (including self-loops) of states connected by (possibly labelled) probabilistic transitions.

Note: The sum of **`%p`** values on all (possibly labelled) probabilistic transitions leaving a vanishing state needs not be equal to 1; if this sum is different from 1, then probabilistic values will be normalized (i.e., divided by this sum).

To build the reduced matrix, **bcg_steady** eliminates all vanishing states, so that this matrix contains tangible states only. The input BCG graph should be such that, after reduction, each tangible state possesses at least one outgoing transition (i.e., there is no deadlock state).

See also **bcg_min**(LOCAL) for a discussion about the various probabilistic and stochastic models present in the literature.

OUTPUT-1: THE SOLUTION VECTOR

The format of the file generated using the **-sol** option of **bcg_steady** is the following. There is one line per tangible state. Each line contains two numbers: an integer corresponding to the state number in the input BCG graph and a real number corresponding to the probability of being in this state on the long run (i.e., at the equilibrium).

OUTPUT-2: THE TRANSITION THROUGHPUTS

The throughput table has two (possibly empty) groups of columns:

- The first group contains one column for each option *parameter*=*value* given on the command-line. These columns, if any, are useful when evaluating the performance of a system parameterized with one or more variables, namely to aggregate in the same table the different throughputs measures corresponding to different values of the parameters. Columns of the first group appear in the same order as the corresponding options on the command-line.

- The second group contains one column per labelled stochastic transition label present in the input BCG graph, precisely, one column for each different *label* occurring on a transition of the form "*label*`; rate %f`".

The throughput table starts with a first "header" line followed by one or several "subsequent" lines.

- The header line contains the "titles" of columns. For a column of the first group associated to a *parameter*=*value* option, the corresponding title is *parameter*. For a column of the second group associated to a label, the corresponding title is the label itself.

- The subsequent lines contain values. For a column of the first group associated to a *parameter=value* option, the corresponding cell contains *value*. For a column of the second group associated to a *label*, the corresponding cell contains the throughput for this label, i.e., the sum, for each stochastic transition "*label*`; rate %f`", of the rate value *%f* weighted with the probability of being in the tangible source state of this transition, in the long run.

If the **-append** option is absent, or if the throughput file is equal to the special string '-', or if the throughput file does not exist, or if it is empty, *bcg_steady* will generate automatically the header line and one single subsequent line.

Otherwise, the first line of the throughput file is expected to contain the titles of columns and will be parsed to identify the correspondance between labels and columns. In particular, **bcg_steady** checks that the first group of columns corresponds to the parameters given on the command-line. After parsing the header line, **bcg_steady** will append one single subsequent line at the end of the throughput file. As regards the second group of columns, if the label of a given column title does not occur in *filename***.bcg**, a zero throughput will be reported in the corresponding column; conversely, labels of *filename***.bcg** for which there is no corresponding column title will be ignored.

Throughputs can be displayed in two different formats, which are determined according to the suffix (i.e., file extension) of the throughput file name.

- If the file name has the "**.csv**" extension, the throughput table will be displayed in the CSV (Comma-Separated Values) exchange format understood by most relational data base applications and spreadsheet software (such as Microsoft Excel, etc.).

- Otherwise, if the file name has a different extension, or no extension, or if it is the standard output, throughputs will be displayed in a human-readable format that is essentially the same format as CSV with commas replaced by spaces so as to align columns properly. Note that this format is also understood by some data visualization tools such as Gnuplot.

OUTPUT-3: THE (TRANSPOSED) MATRICES

Both the (transposed) "raw" matrix produced using option **-mat** and the (transposed) reduced matrix produced using option **-red** follow the same format conventions. The essential difference is that the former contains vanishing and tangible states, whereas the latter only contains tangible states. Also, the reduced matrix is a generator of a continuous-time Markov chain.

For two different indexes i and j, the element (i,j) of the matrix, located at the i-th row and the j-th column, is the sum of all the floating-point numbers associated to the (labelled) stochastic or probabilistic transitions going from the j-th state to the i-th state, where floating-point numbers associated to (labelled) stochastic transitions are interpreted as positive numbers whereas floating-point numbers associated to (labelled) probabilistic transitions are interpreted as negative numbers between -1 and 0. Note that rates and probabilities are never mixed since, between two states, there cannot be stochastic and probabilistic transitions at the same time.

The diagonal elements (j,j) are defined to be the negative sum of all matrix elements (i,j) with i different from j.

Matrices can be displayed in three different formats, which are determined according to the suffix (i.e., file extension) of the matrix file name.

- If the file name has the "**.csv**" extension, the matrix will be displayed in the CSV (Comma-Separated Values) format mentioned above. Each raw of the matrix is displayed on one line of the output file, and on each line, the matrix elements are separated with commas.

- If the file name has the "**.spm**" extension, the matrix will be displayed in the format used by the Sparse 1.3 software library (see the CREDITS section below). This format is the following. The first line of the file contains the file name. The second line contains the number of states, followed by the "**`real`**" keyword. Then, there is one line per each non-zero element (*i*,*j*) in the matrix. Each line contains two integers followed by one real number: the value of *i*, the value of *j*, and the value of matrix element (*i*,*j*). The file ends with a "sentinel" line consisting of three zeros.

- Otherwise, if the file name has a different extension, or no extension, or if it is the standard output, the matrix will be displayed in a human-readable format. The columns of the matrix are split into "packets" so that the text fits on the size of the display. The indexes of rows and columns are indicated and null elements of the matrix are displayed as "..." instead of "0". Statistics (such as matrix size, density, etc.), are displayed after the matrix.

Note: for graphs with many states, whatever the chosen matrix format, the matrix files can be large and writing them to disk may take time.

ENVIRONMENT VARIABLES

See the **bcg**(LOCAL) manual page for a description of the environment variables used by all the BCG application tools.

EXIT STATUS

Exit status is 0 if everything is all right, 1 otherwise.

AUTHORS

The first version of **bcg_steady** was written by Christophe Joubert (INRIA/VASY) and Holger Hermanns (Saarland University and University of Twente). The algorithm for steady-state analysis is based on a former implementation by Vassilis Mertsiotakis (University of Erlangen). Bruno Ondet (INRIA/VASY) ported the tool to various architectures. David Champelovier and Hubert Garavel (both at INRIA/VASY) deeply revised the **bcg_steady** code and manual page to allow their integration within CADP. Holger Hermanns and Frederic Lang (INRIA/VASY) proof-checked the manual page.

CREDITS

bcg_steady uses (an extended version of) the Sparse 1.3 package from the University of California, Berkeley, developed by Kenneth S. Kundert under the supervision of Alberto Sangiovanni-Vincentelli.

OPERANDS

filename.**bcg**	BCG graph (input)
filename@**1.o**	dynamic library (input or output)

FILES

$CADP/bin.‘arch‘/bcg_steady	“**bcg_steady**” program

See the **bcg**(LOCAL) manual page for a description of the other files.

SEE ALSO

bcg(LOCAL), **bcg_min**(LOCAL), **bcg_transient**(LOCAL), **determinator**(LOCAL)

Additional information is available from the CADP Web page located at http://cadp.inria.fr

Directives for installation are given in files **$CADP/INSTALLATION_**∗.

Recent changes and improvements to this software are reported and commented in file **$CADP/HISTORY**.

BUGS

Please report bugs to cadp@inria.fr

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