

# Carthagène - User Documentation

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June 4, 2010

## Acknowledgements

The CarthaGène software started out in 1995 from the confrontation of 2 computer scientists and one statistician with a multiple population data-set of backcross-like data. From this initial team, only one computer scientist remains. Thanks to C. Gaspin for respectively incorporating the *genetic algorithm* and B. Mangin for helping us dealing with genetics, pedigree, segregation ratio...

Denis Chenevière entirely implemented a first version of the graphical interface during his CNAM engineer project.

CarthaGène also largely benefited from the interaction with real data (and those that produced the data !). Thanks to Valérie Laurent (and *Trichogramma brassicae*), Vincent Lombard (and *Brassica napus*), to Karim Gharbi (and *Salmo trutta*), to Jean-Francois Rami (private data - Euralis :-), Jean-Paul Bouchet (Aurige et CarthaGène) for their suggestions and the motivation they created.

We would like to conclude with a very special thank for Denis Milan (and *Sus scrofa*) for inviting us in the radiated hybrid world with ImprH. Some of the commands you may appreciate the most in CarthaGène exist mainly because of the interaction with Denis. Watch out for new commands in the future !

A few years later, a new methodology based on comparative mapping is now available thanks to Thomas Faraut who first introduced the idea of a comparative mapping software and who gave the theoretical and algorithmic foundations necessary to achieve this goal. This approach was further extended by Bertrand Servin who proposed to exploit map distributions using Markov Chain Monte Carlo.

One year later, C. Nelson (Univ. Kansas) joined the CarthaGène development team and introduced code for dealing with advanced backcross data (combining backcross, selfing, doubling...).

CarthaGène is entirely open source and is hosted by the G-Forge collaborative development site of the Applied Mathematics and Computer Science Department of the french National Institute for Agronomical Research (INRA), Mulcyber<sup>1</sup>.

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<sup>1</sup><https://mulcyber.toulouse.inra.fr/projects/carthagene/>

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# Introduction

CAR<sub>H</sub><sup>T</sup>AGENE is a computer tool for building genetic and/or radiated hybrid maps. For those who don't know, radiation hybrid mapping is a somatic cell technique which is used for ordering markers and estimating a *physical* distances between them (chromosomes are broken by irradiation) expressed in centiRay (instead of centiMorgan).

The main specificity of CAR<sub>H</sub><sup>T</sup>AGENE lies in the fact that it can build maximum likelihood "consensus" maps for several data sets corresponding to different populations but it can naturally also handle single population mapping.

The main strengths of CAR<sub>H</sub><sup>T</sup>AGENE can be rapidly described as follows:

- it can merge data sets from several types, both genetic and radiated hybrid data, assuming either shared "distances" or not between different populations.
- it always uses maximum multipoint likelihood as the criterion to compare maps, a rigorous well-behaved criterion. With optimized algorithms for backcross and haploid RH data, CAR<sub>H</sub><sup>T</sup>AGENE can, with no loss of precision, be one or two order of magnitude faster than alternative algorithms using the same criterion.
- it contains several powerful algorithm for building and validating both comprehensive and framework maps.
- it does not simply return a supposedly optimal map but a set of the  $k$  best maps that have been encountered during search. This gives feedback on the reliability of a map ordering.
- it has a graphical interface where maps can be visualised and compared and a text interface with an underlying programming language (called Tcl) which can be used to automate mapping. If you intend to develop automated mapping procedure, you can get more documentation on the Tcl language at <http://www.tcl.tk/doc/>. If you prefer, a Perl interface has also been independently developed by W.M. Snelling (USDA).
- it can be used on several platforms (unix, Linux, Windows).

This document is the user guide of CAR<sub>H</sub><sup>T</sup>AGENE. It is intended for any user that would like to use CAR<sub>H</sub><sup>T</sup>AGENE. It essentially describes the textual interface of CAR<sub>H</sub><sup>T</sup>AGENE where commands are issued, the graphical interface is considered to be intuitive enough to be understandable once the textual interface is mastered.

For installing CAR<sub>H</sub><sup>T</sup>AGENE on your system, please go to CAR<sub>H</sub><sup>T</sup>AGENE's home page on the web:

<http://www.inra.fr/bia/T/CarthaGene>.

# Chapter 1

## Quick Start

The following section illustrates some of the major commands of CAR<sub>H</sub>AGENE on small example data sets. This quick start example is done using the shell interface but can also be performed using the graphical interface (either by clicking buttons in most cases, sometimes by issuing the command in the text window). For this QuickStart, we just give here a fast description of CAR<sub>H</sub>AGENE's main principles, you'll find more information in the sequel of the Documentation.

- Handling Data Sets:
  - Data sets are loaded from files formatted as in MapMaker.
  - The current data set used by CarthaGene to compute maps, is always the last data set which has been “created” (loaded or merged).
  - The merging operators (`dsmergen`, `dsmergor`) accept only two data sets. You will have to call them several times to merge more than two data sets.
  - A list of implicitly selected loci is always active. By default this list contains all the markers of the last data set created (loaded or merged). The user can change this selection of loci (`mrksselset`) if he wants to build maps with a specific selection of loci.
- Map Search:
  - Each ordering algorithm sends the maps it has computed to a specific storage area called “the heap”.
  - The so-called “heuristics” algorithms start from the data sets and compute maps from scratch..
  - The so-called “Local Search” algorithms, and the verification algorithms start from the best map on the heap and try to improve this map.
- Results exploitation and storage:
  - CarthaGene considers that the result of a map search is the set of the  $k$  best maps found during the session,
  - The heap always keep these  $k$  best solutions.
  - if the hierarchy of data sets changes, the heap becomes obsolete and is emptied.

To start CAR<sub>H</sub>AGENE shell, run the shell of Tcl (`tclsh`). If CAR<sub>H</sub>AGENE is well installed, its functionalities should be available and a message mentioning that CarthaGene has been loaded should appear (the prompt might not be the same, don't worry). Under windows, you can use the graphical interface and directly type your command in the main window.



```
[alta:exemple] tclsh
```

```
CarthaGene version 0.999-LKH, Copyright (c) 1997-2004 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.  
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG>
```

If you type help, the complete list of the commands of CarthaGene will appear.

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.  
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> help
```

```
CartaGene commands :
```

```
=====
```

```
miscellaneous :
```

```
-----
```

cgout	Save the output to a file.
cg2pt	Compute approximated likelihoods based on 2-point estimatio...
cgtolerance	Sets EM convergence thresholds.
cgversion	Get the .
cgrestart	Reset the application.
cgstop	To stop a running command, type ctrl-c.
cglicense	Deprecated command.
cgstat	Get some performance information.
cgnotrobust	Disable reliability test of framework maps.
cg2tsp	Convert current marker selection to TSP.
cgrobustness	Sets reliability threshold for framework maps.
cgsave	Save the state of the current session.
cgexport	Save the state of the current session.

```
to manipulate data sets :
```

```
-----
```

dsclone	Clone a dataset.
dsbp	Compute the number of breakpoints between one order data se...
dsload	Load a Biological Data Set.
dsrhconv	Convert a radiated hybrid dataset into haploid diploid error.
dsbplambda	Replaces the traditional criterion by the comparative mappi...
dsmergor	Merge by order two Biological Data Sets.
dsbpcoef	Modifies the coefficient factor value applied to the number...
dsinfo	Summarize the current data sets.
dsmergen	Merge two Biological Data Sets.
dsget	Get a list of the current data sets description.

```
to manipulate groups :
```

```
-----
```

group	Identify linkage groups.
-------	--------------------------

groupget            Get a group by markers ID.

to manipulate loci :

-----  
mrkdoubleget        Retrive a list of pairs of markers with compatible typing.  
mrklod2p            Print the two points LOD matrix.  
mrkname            Get the name of a locus.  
mrkselget          Return the loci selection into a list.  
mrkid              Get the integer id of a locus.  
mrkallget          Return all the loci into a list.  
mrkfr2p            Print the two points FR/Breaks matrix.  
mrklast            Get the integer id of the last known locus.  
mrkselset          Set the marker list(by Id).  
mrkdist2p          Print the two points distance matrix.  
mrkmerge           Merges two compatible markers.  
mrkdouble          Identifies pairs of markers with compatible typing.  
mrkinfo            Tell which data set each marker belongs to.  
mrkmerget          Retrive a list of merged markers.

to manipulate the heap :

-----  
heapsizeget        get the size of the heap.  
heapsize            Resize the heap.  
heapget            Get the heap, in a list.  
heaprintd          Display the heap in detail, sorted.  
heaprint           Display the heap sorted.  
heaprinto          Display the heap of maps by privileging the order of the ma...  
heapecuisset      enable or disable the equivalence mode of the heap.  
heaprintg          Draw the heap(current best maps) into a graphical display.  
bestprint          Print the best map in the heap.  
bestprintd        Print the best map in the heap, in detail.

to manipulate a map :

-----  
maprint            Print a map.  
mapordget          Get a order of loci from a map, in a list.  
mapbp              Compute the number of breakpoints between one order data se...  
mapocb            Compute the number of obligate chromosome breaks of a map.  
maprintdr          Print a map reverse, in detail.  
mapget            Get a map, in a list.  
maprintd          Print a map, in detail.

to search for good maps :

-----  
greedy            Find good maps using the greedy algorithm.  
lkhocbn           Provide a (nice) map, using normalized 2-points Obligate Ch...  
ilkh1            Provide a (nice) map, using dynamically updated 2-points LO...  
mfmapd           Provide quickly a (nice) map, using the 2-points distances.  
buildfw          Build a framework map.  
ilkh1n           Provide a (nice) map, using dynamically updated normalized ...  
mfmap1           Provide quickly a (nice) map, using the 2-points LOD criteria.  
algogen          Find good maps using the genetic algorithm.  
flips            Try to improve the best map by flipping.  
ilkhocb          Provide a (nice) map, using dynamically updated 2-points Ob...  
lkh              Provide a (nice) map, using 2-points loglikelihoods and Lin...  
ilkh            Provide a (nice) map, using dynamically updated 2-points lo...  
quietset          Make the search process quiet.  
sem              Compute a Single map (Single EM).

polishtest	Try to improve the map giving with markers by polishing.
nicemapd	Provide quickly a (nice) map, using the 2-points distances.
ilkhocbn	Provide a (nice) map, using dynamically updated normalized ...
annealing	Find good maps using the annealing algorithm.
nicemapl	Provide quickly a (nice) map, using the 2-points LOD criteria.
imputation	Impute a genotype-corrected carthagene formatted file (only...
verbset	Make the search process verbose.
lkhd	Provide a (nice) map, using 2-points distances and Lin-Kern...
polish	Try to improve the best map by polishing.
build	Build maps with two-points informations.
lkhocb	Provide a (nice) map, using 2-points Obligate Chromosome Br...
lkhl	Provide a (nice) map, using 2-points LOD criteria and Lin-K...
ilkhhd	Provide a (nice) map, using dynamically updated 2-points di...
lkhn	Provide a (nice) map, using normalized 2-points loglikeliho...

comparative mapping :

-----

paretoplotg	Draw the Pareto frontier.
paretosave	Save the pareto frontier.
paretobestprint	Print the best map in the Pareto frontier.
paretobestprintd	Print the best map in the Pareto frontier, in detail.
paretogreedy	Improve a Pareto frontier approximation.
paretoinfo	Internal command.
paretoheapsize	Set the heap size used by pareto functions.
paretogreedyr	Improve a selection of the Pareto frontier approximation.
paretolkhn	Provide a Pareto frontier approximation.
paretolkh	Provide a Pareto frontier approximation.
paretoinfo	Display the Pareto frontier.
dsbp	Compute the number of breakpoints between one order data se...
dsbplambda	Replaces the traditional criterion by the comparative mappi...
dsbpcoef	Modifies the coefficient factor value applied to the number...
mapbp	Compute the number of breakpoints between one order data se...

graphical commands :

-----

maprintg	Draw a map into a graphical display.
heaprintg	Draw the heap(current best maps) into a graphical display.
paretoplotg	Draw the Pareto frontier.

Type '`<command-name> -H`' for more help with a particular command.

Some commands have a default behaviour :

Type '`d_<command-name>`' to use it.

To change the defaults, edit the '`.carthagenerc`'

## 1.1 Loading data

Now we will begin by loading a dataset. The corresponding command is `textttdsload`. If you want to learn more about this command, you can use the “-H” flag:

```
CG> dsload -H
```

```
Usage : dsload [-h | -H | -u | FileName]
```

```
Description : dsload loads a data set. The file format expected for a biolo...
```

To load the first population (it should be available in the `Data/mouse.raw` file<sup>1</sup> :

```
CG> dsload Data/mouse.raw
{1 intercross 308 46 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
```

Upon loading, CarthaGene computes all the two-points statistics (LOD, distances...) and returns the id of the population, here 1, the type of the population (intercross), the number of individuals (46) and the number of markers (308).

We can now have a look to the the populations loaded using the `dsinfo` (dataset information) command.

```
CG> dsinfo

Data Sets :
-----:
ID          Data Type   markers individuals      filename constraints...
1          intercross    308           46          mouse.raw
```

We can check that the population number 1, the last loaded, is the current population.

We can now give a look to the markers that have been mentioned in the loaded dataset. To display the loci, their numerical id and the data set they come from, we can use the `mrkinfo` command:

```
CG> mrkinfo
...
```

## 1.2 Linkage groups and 2-Points estimations

In CarthaGene, all the two points information (LODs, distances, recombination ratios...) is computed at load time. So we can directly try to group the markers in linkage groups. This is done using the `group` command that specifies a distance and a LOD threshold: two markers whose 2 point distance (Haldane/Ray) is below the given distance threshold and whose 2 points LOD is above the LOD threshold will be put in the same linkage group. Users that don't want to use one of the two thresholds can simply set the threshold they want to ignore to an extreme value (distance threshold set to zero, LOD threshold set to an arbitrary large number).

Let's try this with a 30cM distance threshold and a 3.0 LOD threshold:

```
CG> group 0.3 3.0

Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=30.00:

Group ID : Marker ID List ...
1 : 275
2 : 197
3 : 139
4 : 128 281 259 178 146
5 : 86 265 243 192 116
6 : 54 307 304 295 289 201 177 150 102 96 67
7 : 47 236 48
8 : 30 249 248 234 223 210 173 80 172 287 167 120
9 : 21 303 282 279 242 202 200 185 61 170 26 228 226 224 196 183 16...
```

---

<sup>1</sup>This file has been extracted from the MapMaker 3 distribution.

```

10 : 20 284 277 255 220 239 186 132 99 94 75 85 62 42 38
11 : 18 306 302 305 272 166 131 187 269 271 250 237 144 176 133 90 1...
12 : 17 266 260 257 254 231 247 114 207 225 212 199 188 122 55 110 1...
13 : 15 298 103 27 273 211 208 159 157 115 45 205 164 112
14 : 13 296 276 292 267 263 230 209 153 141 113 100 22 182 299 175 2...
15 : 10 204 245 191 190 184 179 240 221 154 127 123 155 92 91 89 57 ...
16 : 8 41
17 : 7 138 258 219 34 286 280 203 181 149 107 109 74 37 28 29 63
18 : 6 268 308 222 291 235 156 105 39 52 32 104 246 194 158 151 126 ...
19 : 5 262 216 147 117 97 88 12 218 293 300 274 232 171 270 229 206 ...
20 : 4 283 142 56 129 189 134 87 23 244 238 68
21 : 3 72 290 251 193 121 84 40 162 137 71 16 50 233 174
22 : 2 294 297 256 241 143 140 217 252 227 119 136 70 14 11 64
23 : 1 301 264 165 125 124 35 278 214 213 9 111 66 59 198

```

23

In this case, we get 23 groups. In the sequel we will work on the group 10. To focus on this specific group, we will get the list of the markers in the group using the `groupget` command and then select them using the `mrkselset` command. This can be achieved easily in the graphical interface with a few clicks. If you use the shell, do as follows:

```

CG> groupget 10
20 284 277 255 220 239 186 132 99 94 75 85 62 42 38

```

To automagically select the markers of the group, one can use the following syntax (using [ and ]) that simply replaces what appears between [ and ] with the result of the command in between (this is called a macro-expansion). We can therefore select the group 10 with the following command:

```

CG> mrkselset [groupget 10]

```

Note that the current marker selection is not only a set of markers but also a default markers ordering. We can look at the LOD matrix between each pair of markers using the `mrklod2p` command.

```

CG> mrklod2p

```

	20	284	277	255	220	239	186	132	99	94	75...
	L029	A079	A059	A036	M232	D022	M237	M030	M076	M034	T018...
L029	-----	4.4	5.5	1.1	4.4	6.3	2.0	4.0	2.0	1.1	3.6...
A079	4.4	-----	18.4	7.4	16.5	5.7	10.5	21.7	10.5	7.4	14.0...
A059	5.5	18.4	-----	6.2	14.2	6.4	9.0	17.8	9.0	6.2	11.9...
A036	1.1	7.4	6.2	-----	9.0	2.6	13.0	7.7	13.0	21.4	8.6...
M232	4.4	16.5	14.2	9.0	-----	4.8	13.0	16.0	13.0	9.0	17.8...
D022	6.3	5.7	6.4	2.6	4.8	-----	3.2	5.2	3.2	2.6	4.5...
M237	2.0	10.5	9.0	13.0	13.0	3.2	-----	11.0	19.9	13.0	12.8...
M030	4.0	21.7	17.8	7.7	16.0	5.2	11.0	-----	11.0	7.7	13.5...
M076	2.0	10.5	9.0	13.0	13.0	3.2	19.9	11.0	-----	13.0	12.8...
M034	1.1	7.4	6.2	21.4	9.0	2.6	13.0	7.7	13.0	-----	8.6...
T018	3.6	14.0	11.9	8.6	17.8	4.5	12.8	13.5	12.8	8.6	-----
T035	13.6	7.2	8.8	2.6	7.4	9.6	4.0	6.8	4.0	2.6	6.5...
L078	13.9	6.9	8.4	2.5	7.1	9.8	3.9	6.5	3.9	2.5	6.2...
L001	5.9	16.8	19.9	6.6	15.1	6.4	9.6	16.3	9.6	6.6	12.8...
L010	18.1	4.3	5.5	1.3	4.3	5.4	2.2	3.9	2.2	1.3	3.5...

Two-points LOD are also used in the `mrkdouble` command which detects pairs of markers that have *compatible* genotypes on each individuals. Such pairs of markers should be merged in one marker to simplify the search for an optimal map. See the 1.8 section on this topic. In practice, two markers can be compatible on all individuals and nevertheless be unlinked. In this case they should not be merged together.

```
CG> mrkdouble
```

Possible double markers:

```

L029 = L010      [18.1]
A079 = M030      [21.7]
A036 = M034      [21.4]
M237 = M076      [19.9]
T035 = L078      [21.4]

```

You see that 5 pairs of markers are “double markers”. We will ignore this issue for now and work on the whole group.

We can also have a look to the 2-points distance matrix using the `mrkdist2p` command. Haldane (h) or Kosambi (k) can be used. Ray distance is automatically selected for radiated hybrid data (whether you specify h or k).

```
CG> mrkdist2p h
```

Print two points distance matrices of the loci selection :

-----;

Data Set Number 1 :

	L029	A079	A059	A036	M232	D022	M237	M030	M076	M03...
L029	29.9	25.3	61.8	28.2	10.0	43.4	31.1	43.4	61....	
A079	29.9	2.2	17.9	3.4	13.2	10.0	0.0	10.0	17....	
A059	25.3	2.2	21.6	5.9	10.6	13.0	2.3	13.0	21....	
A036	61.8	17.9	21.6	13.0	29.8	5.9	16.6	5.9	0....	
M232	28.2	3.4	5.9	13.0	15.9	5.9	3.5	5.9	13....	
D022	10.0	13.2	10.6	29.8	15.9	22.5	13.9	22.5	29....	
M237	43.4	10.0	13.0	5.9	5.9	22.5	8.8	0.0	5....	
M030	31.1	0.0	2.3	16.6	3.5	13.9	8.8	8.8	16....	
M076	43.4	10.0	13.0	5.9	5.9	22.5	0.0	8.8	5....	
M034	61.8	17.9	21.6	0.0	13.0	29.8	5.9	16.6	5.9	
T018	30.5	4.9	7.6	12.2	1.2	16.0	4.9	5.0	4.9	
T035	6.0	18.4	14.8	40.0	16.7	2.4	27.4	18.9	27.4	
L078	5.9	19.6	16.1	41.5	18.0	2.4	28.9	20.3	28.9	
L001	23.4	3.4	1.1	19.8	4.6	10.4	11.5	3.5	11.5	
L010	0.0	26.3	21.4	51.1	24.3	6.5	36.8	27.4	36.8	

You can also look to 2-points recombination ratio (breakage ratio for RH data) using `mrkfr2p`:

```
CG> mrkfr2p
```

Print two-points recombination-fraction matrices of the locus selection :

-----;

	L029	A079	A059	A036	M232	D022	M237	M030	M076	M034	T018	T...
L029	0.225	0.199	0.355	0.215	0.091	0.290	0.231	0.290	0.355	0.228	0....	
A079	0.225	0.022	0.151	0.033	0.116	0.091	0.000	0.091	0.151	0.046	0....	
A059	0.199	0.022	0.175	0.056	0.095	0.115	0.022	0.115	0.175	0.070	0....	
A036	0.355	0.151	0.175	0.115	0.225	0.056	0.142	0.056	0.000	0.108	0....	
M232	0.215	0.033	0.056	0.115	0.136	0.056	0.034	0.056	0.115	0.011	0....	
D022	0.091	0.116	0.095	0.225	0.136	0.181	0.121	0.181	0.225	0.137	0....	

```

M237 |0.290 0.091 0.115 0.056 0.056 0.181 -----0.081 0.000 0.056 0.047 0....
M030 |0.231 0.000 0.022 0.142 0.034 0.121 0.081 -----0.081 0.142 0.048 0....
M076 |0.290 0.091 0.115 0.056 0.056 0.181 0.000 0.081 -----0.056 0.047 0....
M034 |0.355 0.151 0.175 0.000 0.115 0.225 0.056 0.142 0.056 -----0.108 0....
T018 |0.228 0.046 0.070 0.108 0.011 0.137 0.047 0.048 0.047 0.108 -----0....
T035 |0.057 0.154 0.128 0.275 0.142 0.024 0.211 0.158 0.211 0.275 0.150 --...
L078 |0.056 0.162 0.137 0.282 0.151 0.023 0.219 0.167 0.219 0.282 0.160 0....
L001 |0.187 0.033 0.011 0.163 0.044 0.094 0.103 0.034 0.103 0.163 0.058 0....
L010 |0.000 0.204 0.174 0.320 0.192 0.061 0.261 0.211 0.261 0.320 0.206 0....

```

### 1.3 Building maps from scratch

We can now start to try to build maps. All the maps built go in a specific storage structure called the “heap” that remembers the  $k$  best maps found during all the map search process. To build a first map in order to get a first map in the heap, we will simply directly ask CarthaGene to assess the quality of the default order specified in the `mrkselset` command. This is done using the `sem` command. This procedure compute true multipoint maximum likelihood of the current order and prints the corresponding map (the markers order used for printing can be reversed w.r.t. the marker selection. See section 2.4.10).

```

CG> sem

Map -1 : log10-likelihood =  -169.89
-----:
Set : Marker List ...
1 : L029 A079 A059 A036 M232 D022 M237 M030 M076 M034 T018 T035 L078 L00...

```

To try to build less stupid maps, we can try to use heuristics building procedures. The two simple procedures `nicemapl` and `nicemapd` build reasonably good maps using respectively 2-points LOD and 2-points distances as guide (trying to put strong LOD/small distances close together). The two slightly more complex procedures `mfmapl` and `mfmapd` tend to provide better results. Both classes of heuristics are derived from usual travelling salesman problem heuristics. In all cases, the true multipoint maximum likelihood of the order is then computed and the map printed.

```

CG> nicemapl

Map -1 : log10-likelihood =  -72.96
-----:
Set : Marker List ...
1 : L029 L010 L078 T035 D022 A059 L001 A079 M030 M232 T018 M237 M076 A03...

CG> nicemapd

Map -1 : log10-likelihood =  -70.86
-----:
Set : Marker List ...
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...

```

The loglikelihoods of the maps found using these two heuristics are -72.96 and -70.86 respectively. We can have a closer look to the maps build up to this point by asking for a detailed view of all the maps stored in “the heap”. This is achieved using the `heaprintd` command:

```

CG> heaprintd

Map 0 : log10-likelihood =  -169.89, log-e-likelihood =  -391.19

```

-----:

Data Set Number 1 :

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%age)	2pt LOD
1	20	L029	29.9 cM	0.0 cM	24.3 cM	22.5 %%	4.4
2	284	A079	2.2 cM	29.9 cM	2.2 cM	2.2 %%	18.4
3	277	A059	21.6 cM	32.2 cM	18.3 cM	17.5 %%	6.2
4	255	A036	13.0 cM	53.7 cM	11.7 cM	11.5 %%	9.0
5	220	M232	10.1 cM	66.8 cM	9.2 cM	9.1 %%	4.8
6	239	D022	13.9 cM	76.9 cM	12.4 cM	12.2 %%	3.2
7	186	M237	8.7 cM	90.8 cM	8.0 cM	7.9 %%	11.0
8	132	M030	8.7 cM	99.4 cM	8.0 cM	7.9 %%	11.0
9	99	M076	5.9 cM	108.1 cM	5.6 cM	5.6 %%	13.0
10	94	M034	12.2 cM	114.0 cM	11.0 cM	10.9 %%	8.6
11	75	T018	19.3 cM	126.3 cM	16.6 cM	16.0 %%	6.5
12	85	T035	0.0 cM	145.6 cM	0.0 cM	0.0 %%	21.4
13	62	L078	14.5 cM	145.6 cM	12.8 cM	12.6 %%	9.0
14	42	L001	19.4 cM	160.0 cM	16.6 cM	16.1 %%	6.0
15	38	L010	-----		-----		
			179.4 cM		156.8 cM		

15 markers, log10-likelihood = -169.89  
log-e-likelihood = -391.19

Map 1 : log10-likelihood = -72.96, log-e-likelihood = -167.99  
-----:

Data Set Number 1 :

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%age)	2pt LOD
1	20	L029	0.0 cM	0.0 cM	0.0 cM	0.0 %%	18.1
2	38	L010	5.9 cM	0.0 cM	5.6 cM	5.6 %%	13.1
3	62	L078	0.0 cM	5.9 cM	0.0 cM	0.0 %%	21.4
4	85	T035	2.8 cM	5.9 cM	2.7 cM	2.7 %%	9.6
5	239	D022	12.7 cM	8.7 cM	11.4 cM	11.2 %%	6.4
6	277	A059	1.1 cM	21.4 cM	1.1 cM	1.1 %%	19.9
7	42	L001	3.4 cM	22.5 cM	3.3 cM	3.3 %%	16.8
8	284	A079	0.0 cM	25.9 cM	0.0 cM	0.0 %%	21.7
9	132	M030	3.4 cM	25.9 cM	3.3 cM	3.3 %%	16.0
10	220	M232	1.1 cM	29.3 cM	1.1 cM	1.1 %%	17.8
11	75	T018	4.7 cM	30.4 cM	4.5 cM	4.5 %%	12.8
12	186	M237	0.0 cM	35.1 cM	0.0 cM	0.0 %%	19.9
13	99	M076	5.9 cM	35.1 cM	5.6 cM	5.6 %%	13.0
14	255	A036	0.0 cM	41.0 cM	0.0 cM	0.0 %%	21.4
15	94	M034	-----		-----		
			41.0 cM		38.6 cM		

15 markers, log10-likelihood = -72.96  
log-e-likelihood = -167.99

Map 2 : log10-likelihood = -70.86, log-e-likelihood = -163.17



```
-----:
```

```
Data Set Number 1 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	20	L029	0.0 cM	0.0 cM	0.0 cM	0.0 %%	18.1
2	38	L010	5.9 cM	0.0 cM	5.6 cM	5.6 %%	13.1
3	62	L078	0.0 cM	5.9 cM	0.0 cM	0.0 %%	21.4
4	85	T035	2.5 cM	5.9 cM	2.5 cM	2.5 %%	9.6
5	239	D022	11.5 cM	8.5 cM	10.4 cM	10.2 %%	6.4
6	42	L001	1.1 cM	19.9 cM	1.1 cM	1.1 %%	19.9
7	277	A059	2.2 cM	21.0 cM	2.2 cM	2.2 %%	18.4
8	284	A079	0.0 cM	23.3 cM	0.0 cM	0.0 %%	21.7
9	132	M030	3.4 cM	23.3 cM	3.3 cM	3.3 %%	16.0
10	220	M232	1.1 cM	26.7 cM	1.1 cM	1.1 %%	17.8
11	75	T018	4.7 cM	27.8 cM	4.5 cM	4.5 %%	12.8
12	186	M237	0.0 cM	32.5 cM	0.0 cM	0.0 %%	19.9
13	99	M076	5.9 cM	32.5 cM	5.6 cM	5.6 %%	13.0
14	255	A036	0.0 cM	38.4 cM	0.0 cM	0.0 %%	21.4
15	94	M034	-----		-----		
			38.4 cM		36.2 cM		

```
15 markers, log10-likelihood = -70.86
log-e-likelihood = -163.17
```

```
EM calls:
Set 1 : 36 (33,0)
CPU Time (secs): 0.02
Maps within -3.0: 2
```

So far there are only our 3 maps in the heap. We can try to build other maps using a smarter heuristics procedure called `build`. This command incrementally includes markers, always choosing the best loglikelihood and the best insertion point. Because it is too “greedy” in its choices, this procedure can be performed in parallel on several maps, always keeping the  $k$  best maps. So, the command takes one parameter  $k$  to specify the number of map built at the same time.

```
CG> build 10
```

```
Build(10) : |||||
```

```
Map 5 : log10-likelihood = -70.86
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...
```

No better map was found. We may now shift to so-called “improving” methods. These methods cannot start from scratch and are dedicated at improving available maps.

## 1.4 Map improving methods

As a first trial, we can use the local search algorithms. In this example, we will use the “simulated annealing” algorithm embodied in the `annealing` command. The command takes some parameters to specify

how the search takes place (and how much cpu-time it will consume). Here we use 100 moves per level (the larger the better the search and the more expensive it is), an initial temperature of 50 (this is automatically reajusted), a final temperature of 0.1 (the smaller, the better the search and the more expensive too) and a cooling factor of 0.8 (always strictly less than 1, the closer to 1, the better the search and the more expensive too). This a very fast search (use other parameters in practice).

```
CG> annealing 100 50 0.1 0.8
```

```
Map -1 : log10-likelihood = -70.86
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...
```

```
Temp: 50.00 :
```

```
Temp: 40.00 :
```

```
Temp: 32.00 :
```

```
Temp: 25.60 :
```

```
Temp: 20.48 :
```

```
Temp: 16.38 :
```

```
Temp: 13.11 :
```

```
Temp: 10.49 :
```

```
Temp: 8.39 :
```

```
Temp: 6.71 :
```

```
Temp: 5.37 :
```

```
Temp: 4.29 :
```

```
Temp: 3.44 :
```

```
Temp: 2.75 :
```

```
Temp: 2.20 :
```

```
Temp: 1.76 :
```

```
Temp: 1.41 :
```

```
Temp: 1.13 :
```

```
Temp: 0.90 :
```

```
Temp: 0.72 :
```

```
Temp: 0.58 :
```

```
Temp: 0.46 :
```

```
Temp: 0.37 :
```

```
Temp: 0.30 :
```

```
Temp: 0.24 :
```

```
Temp: 0.19 :
```

```
Temp: 0.15 :
```

```
Temp: 0.12 :
```

When the annealing process improves over the best known solution, a “+” is printed. In our case, no better map could be found. Now we would like to see the best maps found (which are stored in the heap), ordered by loglikelihood:

```
CG> heaprint
```

```
Map 0 : log10-likelihood = -70.86
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : L010 L029 L078 T035 D022 L001 A059 M030 A079 M232 T018 M076 M237 A03...
```

```
Map 2 : log10-likelihood = -70.86
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : L010 L029 L078 T035 D022 L001 A059 M030 A079 M232 T018 M237 M076 A03...
```

```

Map 14 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L010 L029 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...

Map  6 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L010 L029 L078 T035 D022 L001 A059 A079 M030 M232 T018 M076 M237 A03...

Map  1 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 T035 L078 D022 L001 A059 M030 A079 M232 T018 M076 M237 A03...

Map  3 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 T035 L078 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...

Map  4 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 T035 L078 D022 L001 A059 A079 M030 M232 T018 M076 M237 A03...

Map  7 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 M030 A079 M232 T018 M237 M076 M03...

Map  8 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 M030 A079 M232 T018 M076 M237 A03...

Map 13 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 M030 A079 M232 T018 M076 M237 M03...

Map  5 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 M030 A079 M232 T018 M237 M076 A03...

Map 10 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 M03...

Map  9 : log10-likelihood =   -70.86
-----:
Set : Marker List ...
    1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M076 M237 A03...

Map 12 : log10-likelihood =   -70.86
-----:
Set : Marker List ...

```

```

1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M237 M076 A03...
Map 11 : log10-likelihood = -70.86
-----:
Set : Marker List ...
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M076 M237 M03...

```

The best map is always the last map. We see that on this data set there are several maps with different orders and a close (or equal) likelihood. This is not surprising if you remember that the `mrkdouble` command detected several “double” markers. Usually, swapping 2 “double markers” in a map will not change the loglikelihood.

Another local search algorithm is the “taboo search” algorithm embodied in the `greedy` command. The command takes some parameters to specify how the search takes place (and how much cpu-time it will consume). Here we use 3 loops (the larger the better the search and the more expensive it is), an additional number of iterations of 0, the minimum size of the taboo list is 1% of the neighborhood and the maximum size of the list is 15%.

```

CG> greedy 3 1 1 15 0

Map -1 : log10-likelihood = -70.86
-----:
Set : Marker List ...
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M076 M237 A03...
Run number 0
*-----*-----*-----*-----*-----*-----*-----*-----Run number 1
----*-----*-----*-----*-----*-----*-----*-----*-----Run number 2
-----*-----*-----*-----*-----*-----*-----*-----*-----*-----*-----

```

The algorithm prints a ‘-’ when the map could not be improved, a ‘+’ when the best map has improved and a ‘\*’ to say that the search process has detected that it is stuck in a region it has already explored. In this case, it starts from another random order. Here, again, no improvement was obtained. Note that the map improving commands can be used as map validating commands using the `cgrobustness` command (see 2.5.19).

## 1.5 Order validating methods

We can try to test how good this map is using a “verification algorithm”. The usual method of flipping markers inside a window (`ripple` command in `mapmaker`) is called `flips` in `CarthaGene`. It takes 3 parameters: the size of the flipping window, a printing threshold on the difference of loglikelihood with the best map and a last flag that says if the `flips` command must be reiterated if a better map is found. Here we will use a window of 4 markers, all maps whose loglikelihood is better or within 1.0 LOD unit of the loglikelihood of the best map will be printed and the `flips` command will be reiterated on the new improved map if such a map is found.

```

CG> flips 4 1 1

Repeated Flip(window size : 4, threshold : 1.00).

Map -1 : log10-likelihood = -70.86
-----:
Set : Marker List ...
1 : L029 L010 L078 T035 D022 L001 A059 A079 M030 M232 T018 M076 M237 A03...

```

```

      2      2 2 1 2      1 2
2 3 6 8 3 4 7 8 3 2 7 9 8 5 9 log10
0 8 2 5 9 2 7 4 2 0 5 9 6 5 4 -70.86
[1 0 3 2]- - - - - - - - - - -0.00
[- - 3 2]- - - - - - - - - - -0.00
[1 0 - -]- - - - - - - - - - -0.00
- - - - - [- - 3 2]- - - - - -0.00
- - - - - - - - - [- - 3 2]- - 0.00
- - - - - - - - - - [1 0 3 2] 0.00
- - - - - - - - - - [- - 3 2] 0.00

```

Here we see that by flipping markers in the original best map, we have not improved the loglikelihood. We also see that several alternative orders exist. As said before, this is due to the existence of double markers. For example, a line such as [1 0 - -]- - - - - - - - - - -0.00 says that by swapping the first and second markers of the map we don't change the likelihood. These are markers 20 and 38 (top rows). We can ask for the name of these 2 markers:

```

CG> mrkname 20
L029
CG> mrkname 38
L010

```

These two markers were effectively detected as double by the `mrkdouble` command. Ideally, all the previous searches should be repeated after merging the double markers which are strongly linked.

Another validation procedure is the `polish` command. It takes each marker successively and tries to insert it in all possible intervals. The variation in loglikelihood is reported for each marker and each destination interval.

```

CG> polish

```

Local map analysis:

	L029	L010	L078	T035	D022	L001	A059	A079	M030	M232	T018	M...
L029	-----	0.0	12.6	9.5	10.0	27.3	27.3	32.3	26.6	29.5	26.9	3...
L010	0.0	-----	10.5	7.8	9.0	25.2	25.5	30.8	25.0	27.9	25.6	3...
L078	7.6	10.5	-----	0.0	3.3	24.0	24.5	29.9	24.0	26.9	25.2	3...
T035	7.8	10.5	0.0	-----	3.3	22.7	23.4	28.9	23.0	25.9	24.3	3...
D022	4.4	6.8	1.9	3.3	-----	10.4	9.9	14.1	11.1	14.5	12.4	1...
L001	14.6	26.4	19.5	22.7	10.4	-----	2.1	9.0	5.0	10.4	10.9	2...
A059	15.9	28.2	21.3	24.8	12.5	2.1	-----	6.9	5.4	13.3	13.4	2...
A079	17.9	31.5	24.8	28.7	16.7	7.5	6.9	-----	0.0	9.6	10.5	2...
M030	17.7	31.4	24.8	28.7	16.7	7.5	6.9	0.0	-----	9.6	10.4	1...
M232	16.0	29.5	22.8	26.5	16.0	7.2	10.9	8.1	9.6	-----	2.4	1...
T018	15.1	29.2	22.5	26.3	16.8	8.7	13.0	10.2	11.9	2.4	-----	1...
M076	17.8	34.0	27.9	32.7	22.7	15.7	21.2	18.8	20.9	12.9	11.9	----
M237	17.8	34.0	27.9	32.7	22.7	15.7	21.2	18.8	20.9	12.9	11.9	...
A036	20.3	37.5	31.7	37.0	27.4	21.6	28.4	26.1	28.8	21.6	21.8	1...
M034	20.3	37.5	31.7	37.0	27.4	21.6	28.4	26.1	28.8	21.6	21.8	1...

We can see again the 'double' markers effect (with 0.0 LOD differences). Otherwise, all markers seems to be relatively firmly placed with high LODs, all above 2.1.

Let us have a look in detail to the best map, the map 12.

```
CG> maprintd 12
```

```
Map 12 : log10-likelihood = -70.86, log-e-likelihood = -163.17
-----;
```

```
Data Set Number 1 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	20	L029	0.0 cM	0.0 cM	0.0 cM	0.0 %%	18.1
2	38	L010	5.9 cM	0.0 cM	5.6 cM	5.6 %%	13.1
3	62	L078	0.0 cM	5.9 cM	0.0 cM	0.0 %%	21.4
4	85	T035	2.5 cM	5.9 cM	2.5 cM	2.5 %%	9.6
5	239	D022	11.5 cM	8.5 cM	10.4 cM	10.2 %%	6.4
6	42	L001	1.1 cM	19.9 cM	1.1 cM	1.1 %%	19.9
7	277	A059	2.2 cM	21.0 cM	2.2 cM	2.2 %%	18.4
8	284	A079	0.0 cM	23.3 cM	0.0 cM	0.0 %%	21.7
9	132	M030	3.4 cM	23.3 cM	3.3 cM	3.3 %%	16.0
10	220	M232	1.1 cM	26.7 cM	1.1 cM	1.1 %%	17.8
11	75	T018	4.7 cM	27.8 cM	4.5 cM	4.5 %%	12.8
12	186	M237	0.0 cM	32.5 cM	0.0 cM	0.0 %%	19.9
13	99	M076	5.9 cM	32.5 cM	5.6 cM	5.6 %%	13.0
14	255	A036	0.0 cM	38.4 cM	0.0 cM	0.0 %%	21.4
15	94	M034	-----		-----		
			38.4 cM		36.2 cM		

```
15 markers, log10-likelihood = -70.86
log-e-likelihood = -163.17
```

This map will be kept as the best comprehensive map of the group in this tutorial. In practice, longer local search algorithm must be performed and other verification procedures should be used.

## 1.6 Building framework maps

Framework maps are maps that are supposedly firmly ordered (weakly ordered markers are not included). Such maps can be build by CarthaGene using a stepwise marker insertion method called `buildfw`.

This command uses an incremental insertion method. It tries to insert non inserted markers in a current map. For a given marker that could be inserted, it tries to insert the marker at all possible position of the map. The difference in loglikelihood between the best insertion and the second best insertion is used to qualify the marker. The marker inserted in practice is the marker that maximizes this difference and such that this difference is larger than a first threshold (Adding Threshold). The marker is inserted at its optimal position. However, if there are orders whose difference in loglikelihood with this best position is less than a second threshold (the Keep Threshold), they are also kept as possible new starting point for the next marker to be inserted.

Note that the build process may start from an empty map or from an existing order (that must contain at least 3 markers). Finally, when all insertable markers have been inserted, the map is kept aside and the remaining marker are tentatively inserted, one by one, in all possible positions in this map and then removed. For each such marker, the command reports how the loglikelihood changes wrt to the best inseryion point. The best position is marked with a “+”. The difference in loglikelihood between the best position and each position are printed out if this difference is less than a threshold. When the last parameter of `buildfw` is set to 0, this last step (testing all remaining loci) is not performed. More complex postprocessing are possible, see the reference user documentation.

Let us test this command on our data. We will use a Keep and Adding threshold of 3.0 LODs, starting the build process from the empty map and trying to position remaining markers.

```
CG> buildfw 3 3 {} 1
```

```
BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.
```

```
>>> Delta = 5.23 :
```

```
Map 0 : log10-likelihood = -44.30
-----:
Set : Marker List ...
1 : T035 L001 M237
```

```
>>> Delta = 5.34 , Id = 220, Locus = M232 :
```

```
Map 0 : log10-likelihood = -47.13
-----:
Set : Marker List ...
1 : T035 L001 M232 M237
```

```
>>> Delta = 4.01 , Id = 255, Locus = A036 :
```

```
Map 0 : log10-likelihood = -55.54
-----:
Set : Marker List ...
1 : T035 L001 M232 M237 A036
```

```
>>> Delta = 3.53 , Id = 284, Locus = A079 :
```

```
Map 0 : log10-likelihood = -59.57
-----:
Set : Marker List ...
1 : T035 L001 A079 M232 M237 A036
```

```
>>> Delta = 3.21 , Id = 20, Locus = L029 :
```

```
Map 0 : log10-likelihood = -67.59
-----:
Set : Marker List ...
1 : L029 T035 L001 A079 M232 M237 A036
```

```
BuildFW, remaining loci test :
```

	2 2 1 2		Lod2pt		Dist2pt					
	2 8 4 8 2 8 5		Left<-M->Right		Left<-M->Right		0->N	N->M	W...	
	0 5 2 4 0 6 5									
A059	2 +		19.88	18.40	1.1	2.2	20.3	1.1	...	
D022	2 +		9.64	6.37	2.4	10.4	6.3	2.6	...	
M030	0 +		21.67	15.97	0.0	3.5	23.7	0	...	
M076		+ 0	12.97	19.87	5.9	0.0	33.1	0	...	
M034		+ 0	12.97	21.37	5.9	0.0	39.0	0	...	
T018		2 +	17.79	12.82	1.2	4.9	27.1	1.1	...	
L078	+ 0		13.87	21.37	5.9	0.0	6.3	0	...	
L010	0 +		18.06	12.85	0.0	4.1	0.0	0	...	

Here the map produced contains only 7 markers. The additional uninserted markers list (A059, D022, M030, M076, M034, T018, L078, L010) contain all the 5 “possible double markers” identified by the

mrkdouble command which is good news. The final map produced is automatically used as the best map. It is supposed to be firmly ordered as we can check with a `flips` command:

```
CG> flips 6 3.0 1
```

```
Repeated Flip(window size : 6, threshold : 3.00).
```

```
Map -1 : log10-likelihood =    -67.59
-----:
Set : Marker List ...
    1 : L029 T035 L001 A079 M232 M237 A036

        2 2 1 2
    2 8 4 8 2 8 5   log10
    0 5 2 4 0 6 5    -67.59
```

which finds no better order at 3.0 LOD units.

We can check with a `polish` command:

```
CG> polish
```

```
Local map analysis:
```

	L029	T035	L001	A079	M232	M237	A036
L029	-----	3.2	19.9	21.1	19.9	23.2	12.3
T035	3.2	-----	16.7	18.4	18.1	23.0	14.2
L001	13.0	16.7	-----	3.5	7.2	15.7	12.3
A079	13.9	19.6	3.5	-----	4.1	13.3	10.9
M232	14.6	20.2	5.7	4.1	-----	10.0	10.0
M237	15.0	24.0	12.6	13.7	10.0	-----	4.0
A036	11.9	22.4	12.9	15.8	13.2	4.0	-----

which finds no better order at 3.0 LOD units.

To check the quality of the map even more thoroughly, we can use map improving commands such as `annealing` or `greedy`. In the process of trying to improve the current framework map, these commands may identify a map whose loglikelihood, if not better than the current map's loglikelihood, may still be close enough to prove that the current map is not a valid framework map. In order to stop the search process as soon as such a map is found, we can use the `cgrobustness` command. The threshold given to the command indicates that every search should stop as soon as a map is found whose loglikelihood is within the threshold of the best map's loglikelihood.

```
CG> cgrobustness 3.0
```

We now try to improve the map using the `greedy` command.

```
CG> greedy 1 0 5 30
```

```
Map -1 : log10-likelihood =    -67.59
-----:
Set : Marker List ...
```



```

1 : L029 T035 L001 A079 M232 M237 A036
Run number 0
-----*****-----

```

which does not find any counter-example that proves that our map is not a framework map. We now remove the previous threshold using the `cgnorobust` command:

```
CG> cgnorobust
```

## 1.7 Merging data sets

Now, we want to merge two different dataset (populations) into one. Two types of merging are available:

- `dsmergen`: merges the two dataset completely. For a given pair of successive markers in the order, the probabilistic model for the data has one single recombination ratio estimation for the 2 datasets. This produces consensus maps with consensus distances<sup>2</sup>.
- `dsmergor`: merges two datasets by order only. For a given pair of successive markers in the order, the probabilistic model for the data has one single recombination ratio estimation for each of the 2 datasets. This produces consensus orders with per data set distances.

In this tutorial, we will merge two data sets by “order” which is the most complex case. The merge by order process is used because we want to merge genetic recombination data and radiated hybrid data and there is no simple way of relating the 2 distances (RH data being essentially physical). Actually, genetic and RH data nicely complement each other for *ordering* markers. Genetic data leads to myopic ordering: set of close markers cannot be reliably ordered because usually no recombination can be observed between them. On the contrary RH data leads to hypermetropic ordering: set of closely related markers can be reliably ordered but distant groups are sometimes difficult to order because too many breaks occurred between them. The data used here is coming from a single group representing one porcine chromosome.

First, let us examine each dataset independently and see what the `buildfw` command can produce from each of these. We first reinitialize CarthaGene using the `cgrestart` command (to keep markers numerical Ids low) and load the new data-set:

```

CG> cgrestart

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> buildfw 3.0 3.0 {} 1

BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.

>>> Delta = 31.90 :

Map 0 : log10-likelihood = -51.48
-----:
Set : Marker List ...
1 : MS4 MS6 MS11

>>> Delta = 7.67 , Id = 12, Locus = MS9 :

```

---

<sup>2</sup>When used on two data sets of the same type, this merging process corresponds to the addition of information on new individuals (on new or known markers). It must not be used when new markers are types on existing individuals. In this case, the data-set file must directly be edited by adding new lines for the new markers (and changing the number of markers in the header).

```

Map 0 : log10-likelihood = -96.95
-----:
Set : Marker List ...
1 : MS4 MS6 MS9 MS11

>>> Delta = 9.58 , Id = 17, Locus = MS1 :

Map 0 : log10-likelihood = -140.24
-----:
Set : Marker List ...
1 : MS11 MS9 MS6 MS4 MS1

>>> Delta = 10.74 , Id = 10, Locus = MS2 :

Map 0 : log10-likelihood = -152.41
-----:
Set : Marker List ...
1 : MS11 MS9 MS6 MS4 MS2 MS1

>>> Delta = 8.28 , Id = 7, Locus = MS16 :

Map 0 : log10-likelihood = -189.08
-----:
Set : Marker List ...
1 : MS16 MS11 MS9 MS6 MS4 MS2 MS1

>>> Delta = 10.24 , Id = 14, Locus = MS12 :

Map 0 : log10-likelihood = -198.74
-----:
Set : Marker List ...
1 : MS16 MS12 MS11 MS9 MS6 MS4 MS2 MS1

>>> Delta = 8.34 , Id = 16, Locus = MS19 :

Map 0 : log10-likelihood = -237.36
-----:
Set : Marker List ...
1 : MS19 MS16 MS12 MS11 MS9 MS6 MS4 MS2 MS1

>>> Delta = 8.20 , Id = 13, Locus = MS15 :

Map 0 : log10-likelihood = -242.13
-----:
Set : Marker List ...
1 : MS19 MS16 MS15 MS12 MS11 MS9 MS6 MS4 MS2 MS1

>>> Delta = 6.61 , Id = 2, Locus = MS5 :

Map 0 : log10-likelihood = -244.22
-----:
Set : Marker List ...
1 : MS19 MS16 MS15 MS12 MS11 MS9 MS6 MS5 MS4 MS2 MS1

>>> Delta = 3.98 , Id = 8, Locus = MS8 :

Map 0 : log10-likelihood = -253.89
-----:

```

```
Set : Marker List ...
1 : MS19 MS16 MS15 MS12 MS11 MS9 MS8 MS6 MS5 MS4 MS2 MS1
```

BuildFW, remaining loci test :

	1	1	1	1	1	1	1	1	1	1	1	Lod2pt	Dist2pt	0->N	...
	6	7	3	4	5	2	8	4	2	1	0	Left<-M->Right	Left<-M->Right		
MS13					0	+						18.66	11.91	0.0	43.3...
MS17	2	+										14.06	6.31	7.4	0.0...
MS7							+	3				35.05	17.32	5.7	63.7...
MS3									+	2		35.05	47.62	5.7	79.6...
MS20	+	1										-	34.83	-	...

The BC dataset is a good quality dataset. Few markers could not be placed in the framework map. The “quality” of this map should naturally be checked more thoroughly using other “validating” and “improving” commnds. We now perform the same analysis on RH data:

```
CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> buildfw 3.0 3.0 {} 1
```

BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.

```
>>> Delta = 5.13 :
```

```
Map 0 : log10-likelihood = -68.70
-----:
Set : Marker List ...
2 : MS4 G40 G39
```

```
>>> Delta = 6.14 , Id = 18, Locus = G36 :
```

```
Map 0 : log10-likelihood = -77.85
-----:
Set : Marker List ...
2 : MS4 G36 G40 G39
```

```
>>> Delta = 3.91 , Id = 4, Locus = MS6 :
```

```
Map 0 : log10-likelihood = -101.52
-----:
Set : Marker List ...
2 : MS6 MS4 G36 G40 G39
```

```
>>> Delta = 3.65 , Id = 12, Locus = MS9 :
```

```
Map 0 : log10-likelihood = -125.81
-----:
Set : Marker List ...
2 : MS9 MS6 MS4 G36 G40 G39
```

BuildFW, remaining loci test :

	1	1	2	1	1	1	1	1	1	1	1	Lod2pt	Dist2pt	0->N	N->M	Wei...
	2	4	1	8	1	9						Left<-M->Right	Left<-M->Right			
MS5	2	+										7.44	3.64	54.3	29.4	...

MS8	+ 0			-	18.48	-	16.5		-	16.5		...
MS7	+ 3			5.44	12.79	72.3	29.5		0.0	57.8		...
MS3		+ 0		9.84	9.69	45.2	45.9		205.2	23.5		...
MS15	+			1	0.99	-	159.0		-	159.0		...
MS1	3			+	3.76	-	89.6		252.7	89.6		...
G37		3 +		15.04	7.23	24.9	59.2		205.2	14.0		...

Since radiated hybrid data usually have very few missing information, it is possible to use specific ordering methods to build very good maps. Several commands in `CARTHAGENE` can directly translate a RH dataset into a specific travelling salesman problem instance such that the optimal solution of this TSP instance will also yield the optimal map. This translation [BDCP00] is faithful when there is no missing information but is still very effective when few missing exists. `CARTHAGENE` automatically reevaluates all the maps generated using multi-point maximum log-likelihood. Here we will try to reorder the framework map we built using the `lkh` command (lk stands for Lin-Kernighan heuristics [LK73, Hel00], a famous algorithm used to solve travelling salesman problem instances.):

```
CG> lkh 1 1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...

Map -1 : log10-likelihood = -125.81
-----:
Set : Marker List ...
    2 : MS9 MS6 MS4 G36 G40 G39
```

The same map with a  $-125.81$  loglikelihood is found which is a very good indication that the order is indeed optimal.

The RH dataset is less order informative than the BC dataset. However, merging the two data sets will help in ordering the markers. Because we are merging populations with not directly related parameters (RH and genetic distances), we will use the `dsmergor` command. The command takes two parameters that specify the numerical id of the two populations to be merged. To see the numerical ids, we can use `dsinfo`.

```
CG> dsinfo

Data Sets :
-----:
ID      Data Type      markers individuals      filename constraints...
1      f2 backcross      17          208          bc1.cg
2      haploid RH        13          118          rh1.cg

CG> dsmergor 1 2
{3 merged by order 21 326}
CG> dsinfo

Data Sets :
-----:
ID      Data Type      markers individuals      filename constraints...
1      f2 backcross      17          208          bc1.cg
2      haploid RH        13          118          rh1.cg
3      merged by order    21          326          ...
```

To better see how markers are shared between the 2 populations, we can use the `mrkinfo` command:

```
CG> mrkinfo
...
```

We can now try to build a framework map for the hybrid genetic/RH data set.

```
CG> buildfw 3.0 3.0 {} 1
```

```
BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.
```

```
>>> Delta = 33.72 :
```

```
Map 0 : log10-likelihood = -94.33
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS8 MS11
```

```
2 : MS8 G36
```

```
>>> Delta = 9.83 , Id = 12, Locus = MS9 :
```

```
Map 0 : log10-likelihood = -135.63
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS8 MS9 MS11
```

```
2 : MS8 MS9 G36
```

```
>>> Delta = 5.40 , Id = 10, Locus = MS2 :
```

```
Map 0 : log10-likelihood = -179.56
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS2 MS8 MS9 MS11
```

```
2 : MS8 MS9 G36
```

```
>>> Delta = 10.61 , Id = 17, Locus = MS1 :
```

```
Map 0 : log10-likelihood = -239.39
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS1 MS2 MS8 MS9 MS11
```

```
2 : MS1 MS8 MS9 G36
```

```
>>> Delta = 12.02 , Id = 2, Locus = MS5 :
```

```
Map 0 : log10-likelihood = -268.97
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS1 MS2 MS5 MS8 MS9 MS11
```

```
2 : MS1 MS5 MS8 MS9 G36
```

```
>>> Delta = 12.93 , Id = 9, Locus = MS7 :
```

```
Map 0 : log10-likelihood = -299.41
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS1 MS2 MS5 MS7 MS8 MS9 MS11
```

```
2 : MS1 MS5 MS7 MS8 MS9 G36
```

```
>>> Delta = 7.33 , Id = 1, Locus = MS4 :
```

```
Map 0 : log10-likelihood = -329.22
```

```
-----:
```

```
Set : Marker List ...
```

```

1 : MS1 MS2 MS4 MS5 MS7 MS8 MS9 MS11
2 : MS1      MS4 MS5 MS7 MS8 MS9      G36

>>> Delta = 7.24 , Id = 4,  Locus = MS6 :

Map 0 : log10-likelihood = -342.74
-----:
Set : Marker List ...
1 : MS1 MS2 MS4 MS5 MS6 MS7 MS8 MS9 MS11
2 : MS1      MS4 MS5 MS6 MS7 MS8 MS9      G36

BuildFW, remaining loci test :

      |      |      |
      | 1 1      1 1 |      Lod2pt      Dist2pt
      | 7 0 1 2 4 9 8 2 5 8 | Left<-M->Right Left<-M->Right | 0->N      N-...
-----|-----|-----|
MS13 |      |      | + 0 | 11.91      0.00      8.4      0.0 | 403.9      0 ...
MS17 | 0      |      | + 0 | 0.10      0.00     121.7      0.0 | 403.9      0 ...
MS16 |      |      | + 0 | 5.47      0.00      27.5      0.0 | 403.9      0 ...
MS3  | 2 +      |      | 47.62     40.41      0.6      5.7 | 19.0      0...
MS15 |      |      | 0 + | -0.00      -      760.1      - | 403.9     760...
MS12 |      |      | + 0 | 10.93      0.00      11.3      0.0 | 403.9      0 ...
MS20 | 2      |      | + 0 | 0.52      0.00      84.9      0.0 | 403.9      0 ...
MS19 | 1      |      | + 0 | 0.56      0.00      77.0      0.0 | 403.9      0 ...
G39  | 2 2      | 1 1 + | 7.67      -      57.8      - | 403.9     57...
G37  |      |      | + 0 0 | 1.48      0.00     138.3      0.0 | 334.7      0 ...
G40  |      |      | + 0 0 | 1.87      0.00     127.0      0.0 | 334.7      0 ...

```

## 1.8 Dealing with “double markers”

- the two markers are effectively closely related (or the same) on the chromosome. In this case it is a good idea to try to merge them in one since this will simplify the ordering process.
- the two markers are totally unrelated markers in two different populations/panels. In this case, it is not a good idea to merge them. Such markers can often be placed using multipoint maximum likelihood.

```
CG> dsload Data/mouse.raw
...
CG> group 0.3 3.0
...
CG> mrkselset [groupget 10]
...
```

If you issue the `mrkdouble` command, you should see the following:

```
CG> mrkdouble
```

Possible double markers:

L029 = L010	[18.1]
A079 = M030	[21.7]
A036 = M034	[21.4]
M237 = M076	[19.9]
T035 = L078	[21.4]

Let's merge A079 and M030 together. This can be achieved using the `mrkmerge` command. The command actually merges the observation of both markers into one and leaves the other unchanged. The command takes the numerical id of the 2 markers as arguments. If you don't know this numerical id, the command `mrkid` can be used as in the example below.

```
CG> mrkselget
41 305 298 276 241 260 207 153 120 115 96 106 83 63 59
CG> mrkmerge [mrkid A079] [mrkid M030]
Markers 305 and 153 merged in 305.
```

Automatically, the marker 132 has been removed from the list of selected markers:

```
CG> mrkselget
41 305 298 276 241 260 207 120 115 96 106 83 63 59
```

The same can be done with each pair of markers detected as double markers. Note that it is possible that after merging two markers, some previously detected double markers become separated (eg. on BC data, one individual, if marker M1 is typed "1", marker M3 is type "0" and marker M2 is typed "-", then M1-M2 and M2-M3 are two pairs of "double markers" but once M1 and M2 are merged, then M3 cannot be merged with the (m1-M2) pair). Although this is an unlikely situation, CarthaGene checks this in practice and will check compatibility before merging. In the example, all pairs can be merged without problem.

```
CG> mrkmerge [mrkid L029] [mrkid L010]
Markers 41 and 59 merged in 41.
```

```
CG> mrkmerge [mrkid A036] [mrkid M034]
Markers 276 and 115 merged in 276.
```

```
CG> mrkmerge [mrkid M237] [mrkid M076]
Markers 207 and 120 merged in 207.
```

```
CG> mrkmerge [mrkid T035] [mrkid L078]
Markers 106 and 83 merged in 106.
```

```
CG> mrkselget
41 305 298 276 241 260 207 96 106 63
```

```
CG> mrklod2p
```

	41	305	298	276	241	260	207	96	106	63
	L029	A079	A059	A036	M232	D022	M237	T018	T035	L001
L029	-----	4.4	5.5	1.1	4.4	6.3	2.0	3.6	13.6	5.9
A079	4.4	-----	18.4	7.4	16.5	5.7	10.5	14.0	7.2	16.8
A059	5.5	18.4	-----	6.2	14.2	6.4	9.0	11.9	8.8	19.9
A036	1.1	7.4	6.2	-----	9.0	2.6	13.0	8.6	2.6	6.6
M232	4.4	16.5	14.2	9.0	-----	4.8	13.0	17.8	7.4	15.1
D022	6.3	5.7	6.4	2.6	4.8	-----	3.2	4.5	9.6	6.4
M237	2.0	10.5	9.0	13.0	13.0	3.2	-----	12.8	4.0	9.6
T018	3.6	14.0	11.9	8.6	17.8	4.5	12.8	-----	6.5	12.8
T035	13.6	7.2	8.8	2.6	7.4	9.6	4.0	6.5	-----	9.3
L001	5.9	16.8	19.9	6.6	15.1	6.4	9.6	12.8	9.3	-----

We can now try to build a comprehensive map. In this simple case, we just try the `nicemapd` command followed by a `flips 5 0 0`.

```
CG> nicemapd
```

```
Map -1 : log10-likelihood = -68.30
-----:
Set : Marker List ...
4 : L029 T035 D022 L001 A059 A079 M232 T018 M237 A036
```

```
CG> flips 5 0 0
```

```
Single Flip(window size : 5, threshold : 0.00).
```

```
Map -1 : log10-likelihood = -68.30
-----:
Set : Marker List ...
4 : L029 T035 D022 L001 A059 A079 M232 T018 M237 A036

1 2 2 3 2 2 2
4 0 6 6 9 0 4 9 0 7 log10
1 6 0 3 8 5 1 6 7 6 -68.30
```

```
CG> heaprintd
```

```
...
```

The best map found can be printed using `heaprintd`. The best map has number 7. We can later visualize it using the `maprintd` command:

```
CG> maprintd 7
```

```
Map 7 : log10-likelihood = -68.30, log-e-likelihood = -157.26
-----:
```

```
Data Set Number 4 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%age)	2pt LOD
1	59 L010		0.0 cM	0.0 cM	0.0 cM	0.0 %%	-----



1	41	L029	4.0 cM	0.0 cM	3.8 cM	3.8 %%	13.6
2	83	L078	0.0 cM	4.0 cM	0.0 cM	0.0 %%	-----
2	106	T035	2.5 cM	4.0 cM	2.5 cM	2.5 %%	9.6
3	260	D022	11.5 cM	6.5 cM	10.4 cM	10.2 %%	6.4
4	63	L001	1.1 cM	18.0 cM	1.1 cM	1.1 %%	19.9
5	298	A059	2.2 cM	19.1 cM	2.2 cM	2.2 %%	18.4
6	153	M030	0.0 cM	21.3 cM	0.0 cM	0.0 %%	-----
6	305	A079	3.4 cM	21.3 cM	3.3 cM	3.3 %%	16.5
7	241	M232	1.1 cM	24.8 cM	1.1 cM	1.1 %%	17.8
8	96	T018	4.7 cM	25.9 cM	4.5 cM	4.5 %%	12.8
9	120	M076	0.0 cM	30.5 cM	0.0 cM	0.0 %%	-----
9	207	M237	5.9 cM	30.5 cM	5.6 cM	5.6 %%	13.0
10	115	M034	0.0 cM	36.5 cM	0.0 cM	0.0 %%	-----
10	276	A036	-----	-----	-----	-----	-----
			36.5 cM		34.5 cM		

```

10 markers, log10-likelihood = -68.30
log-e-likelihood = -157.26

```

You can see that the merged markers are indicated on the map. Looking onto the heap for altered ordering, the situation has much improved with respect to the previous situation (where several orders with identical log-likelihood existed). We can have a look to the situation using the `heaprinto` command:

```

CG> heaprinto 3 0 0
Loci Id ..... 1 2 2 3 2 2 2
          : 4 0 6 6 9 0 4 9 0 7
          : 1 6 0 3 8 5 1 6 7 6
Loci Pos ..... | | | | | | | | | |
Map Id : log10 : | | | | | | | | | | (Delta lod per set)
  7 : -68.30 : 1 2 3 4 5 6 7 8 9 10 ( 4 )
 13 : 2.03 = 2 1 ( 2.03 )
  8 : 2.09 = 4 3 ( 2.09 )
 10 : 2.37 = 7 6 ( 2.37 )
  9 : 2.54 = 2 0 1 ( 2.53 )
 12 : 2.88 = 1 0 ( 2.87 )
  4 : 2.95 = 2 0 ( 2.95 )
 14 : 3.49 = 5 3 ( 3.49 )
 11 : 4.08 = 1 2 0 ( 4.07 )
  5 : 4.11 = 2 1 4 3 ( 4.11 )
  6 : 4.37 = 9 8 ( 4.37 )
  2 : 4.47 = 4 3 7 6 ( 4.46 )
  3 : 4.62 = 2 0 1 4 3 ( 4.61 )
  1 : 4.86 = 1 0 4 3 ( 4.86 )
  0 : 4.92 = 2 0 4 3 ( 4.92 )

```

CG>

and see that the best alternate map found is at 2 LOD units and is obtained by swapping two markers.

## Chapter 2

# User and reference documentation

When you use `CARHAGENE`, there are three implicit objects that are manipulated by the software that are worth mentioning: these are the current data-set, the current list of selected markers and the current set of the best known maps (also referred to as *the heap*).

Despite the fact that `CARHAGENE` can load several data-sets to work with, there is only one data-set active at a given moment in `CARHAGENE`. This data-set may be a single population data set or a multiple population (or so-called “merged”) data-set. This active data set is always the last data-set that has been created (loaded or merged) . All further computations that will be done will be done with respect to this data set, later referred to as the *active* dataset. Note that the name of the markers in the data-sets are very important since they are used by `CARHAGENE` to determine if two markers in two different data sets are identical or not. Besides its name, each markers will receive a so-called numerical id that is often used by `CARHAGENE`. One can easily go between marker names and marker ids using the `mrkname/mrknames` and `mrkid/mrkids` commands.

Once the populations you intend to work with have been loaded and merged as you want, mapping is essentially a problem of choosing and ordering a set of markers. At any time when you use `CARHAGENE` there is an implicit *list of selected markers* that specify the set of markers you intend to work with. This list is also used as a default markers ordering for some commands (eg. the `sem` command, see section 2.5.2). When a data set is created (loaded or merged), all the markers of this data set are selected. You can visualize and modify this selection (see the `mrkselset` command, section 2.3.14 and the `mrkadd`, `mrksub` and `mrkdel` commands).

The last important object in `CARHAGENE` is the so-called *heap*. The heap is simply a bounded-size container for all the best maps for the current marker selection that have been encountered by `CARHAGENE` during the session. Basically, this means that each time a map likelihood is evaluated by `CARHAGENE`, either inside a complex ordering strategy or following a direct user request, it is considered as a candidate for being kept in the heap. If there is room in the heap or if new map has a better likelihood than the worst map in the heap, then the new map will be stored in the heap for further analysis. Eventually, when enough alternative orders have been considered, the heap can be examined to see how strongly the best order is supported by the data by giving alternative sub-optimal orders that were found during search. The size of the heap is user configurable and defaults to 15 maps. Because the heap is implemented using a nice and efficient data-structure, it can be fairly large (eg. more than 1000 maps) without slowing down the software. So don’t hesitate to change this default of 15 if needed (see the `heapsize` command, section 2.4.2).

The heap has another implicit use: several `CARHAGENE` commands that need a marker ordering (or map) to start with will automatically take the best map of the heap as a starting point. This means that if the heap is empty because you haven’t yet computed the likelihood of any map, these procedures will complain of having no starting point. It is up to you to fill the heap using any map building command (see section 2.5).

## 2.1 Formatting the data

Essentially, CAR<sub>H</sub>TAGENE uses a format inspired by MapMaker [LGA<sup>+</sup>87] for datasets. All datasets are described using two header lines followed by the data itself, one marker being described per line.

The first line indicates the type of the data: backcross, RIL, F2 intercross, outbreds, haploid or diploid radiated hybrids, order... See the following sections for more details.

The second line indicates the size of the data set: number of individual/hybrids typed followed by the number of markers. For compatibility with MapMaker, it may contains 2 further numbers which will be ignored by CAR<sub>H</sub>TAGENE and aliases declaration that will be used by CAR<sub>H</sub>TAGENE to analyze the last section of the file that contains typing data. An alias declaration specify that a given character (eg 0) will be used instead of another default one (eg. A) to specify marker typing data. Such an alias is specified by the statement 0=A in the second line.

The last section contains maker typing data. Each line describe typing data for one given marker, one individual (hybrid) after the other. A line begins with a star character (\*) immediately followed by the marker name separated from the rest of the line using either tabulations or space characters. The rest of the line indicates typing data for the marker for each individual (hybrid), one after the other. The number of individual reported on each line must match the number of individuals indicated in the second line of the file and the number of markers (lines of data) must not be lower than the number of markers indicated in the second line of the file (if extra lines are there, they will be ignored).

The following is an example of an haploid radiation hybrid dataset with 4 markers and 40 hybrids were the default A (Absent) and H (Here) typing characters have been respectively aliased to 0 and 1.

```
data type radiated hybrid
40 4 0 0 1=H 0=A
*N7b 110110110-101100001011011111111000111010
*A11 0101001101101100001011011001111000101110
*N4 11010011011011000010110110011110001111101
*rA20 1101001101101100101011010001111111101010
```

The next section specify which header line and which typing conventions must be used to encode marker data depending on the dataset type.

### 2.1.1 Genetic data sets

#### Backcross data

This is a MapMaker compatible format. CAR<sub>H</sub>TAGENE uses a dedicated boosted EM for backcross data which may be one or two orders or magnitudes faster than a standard EM algorithm without any loss of precision [SCBM01]. It can be used for all crosses with an expected segregation ratio of 1:1, including therefore doubled haploid (DH). All backcross data file must start with the following header line:

```
data type f2 backcross
```

In the case of backcross data, each locus can either be homozygous or heterozygous. These two situations are encoded using the H and A characters respectively. Loci with an unknown status are encoded as -. This encoding can be redefined using aliasing in the second header line (see the beginning of the section).

#### Intercross F2 data

This is a MapMaker compatible format. All F2 (intercross) datasets must start with the following header line:

```
data type f2 intercross
```

Depending on the dominance or codominance of each loci, several situations can be encoded. If we call A and B the two alleles of an heterozygous individual, the descendance can be either:

- homozygous A: this is encoded by the character A.
- homozygous B: this is encoded by the character B.
- heterozygous: this is encoded by the character H.
- know to be not homozygous A: this is encoded by the character C.
- know to be not homozygous B: this is encoded by the character D.
- unknown: this is encoded as -.

This encoding can be redefined using aliasing in the second header line (see the beginning of the section).

### Recombinant inbred lines (RIL) data

These are MapMaker compatible formats. Both self and sib RIL data are handled by CAR<sub>T</sub>HAGENE. Note that since these data types are internally handled as pure backcross data (recombination frequencies being adequately corrected to take into account the fact that the data represent self/sib RIL), it is impossible to completely merge (both on order and recombination frequencies, see the `dsmergen` command, section 2.2.2) ) such data with other genetic data. Use the `dsmergor` command in this case.

Depending on the RIL type (self/sib), the first header line of the format file must be respectively:

```
data type ri self
```

or

```
data type ri sib
```

The characters used to encode RIL data are the same as for backcross data (see section 2.1.1). This encoding can be redefined using aliasing in the second header line (see the beginning of the section).

### Data from arbitrary series of mating operations in line crosses

Mating designs consisting of a series of backcrossing, selfing, random intercrossing, and/or haploid-doubling operations applied to F1 progeny of a cross between two homozygous individuals are accepted. The file header will look like this:

```
data type bs BBSBS
```

where the first `bs` (case-insensitive) is required and the final word on the first line is a variable sequence of letters that denote mating operations. In the example above, two backcrosses are followed by a selfing, another backcross, and a final self. The allowed codes are `b`, `s`, `i`, and `d`, and any sequence of up to *eight* operations is permitted.

If your design ends with a backcross operation, be sure that the recurrent parent is represented by the A character. You can use CarthaGene's aliasing notation to alter the character meanings, as described for the f2 backcross and other mating types.

Don't use this method to analyze a single backcross (coded as `bs b`) or RI design (coded, for the example of an F9, as `bs ssssssss`). For these, the standard CarthaGene types are handled with faster algorithms. The F2 design (coded as `bs s`) is handled at probably about the same speed as if it were coded f2 intercross.

### Phase known outbred data

CARTHAGENE can handle outbred data as far as phases are fixed (either known or fixed to the most probable phases). Such phase known outbred datasets can be handled using different strategies. A first simple method (which ignores part of the information) consists in projecting the information on each parent side: this gives two backcross datasets which can be merged using either the `mergen` or `mergor` command. The first case will aim at computing a consensus map (with consensus distances) while the second one will aim at computing a consensus order with different recombination ratio on each parent. We will not detail this strategy here although it has the advantage of relying on our “Boosted EM” algorithm which means that it will be a lot faster than the approach below. In this section, we describe a more complex encoding which does not ignore any information. All outbred datasets must start with the following header line (same as for intercross data):

```
data type f2 intercross
```

Because the ability to handle outbred data has evolved from a classical intercross situation using Mapmaker syntax, the syntax used to encode such data is currently rather clumsy. This may change one of these days but you’d better not count on it. . .

At one locus, consider the cross of  $F_0|F_1 \times M_0|M_1$  where  $F_0$ ,  $F_1$ ,  $M_0$  and  $M_1$  stand for the alleles on each haplotype of the father and the mother respectively. The genotype of the child obtained may be either  $F_0|M_0$ ,  $F_1|M_0$ ,  $F_0|M_1$  or  $F_1|M_1$ . Depending on the heterozygosity of the parents, or the number of different alleles, on the dominance or codominance of the markers, on the observations available on the child’s phenotype, only a subset of these 4 possibilities is possible. For example, in the “usual” F2 intercross situation, the two parents are heterozygous and bear the same pair of alleles:  $F_0 = M_0 = A$  and  $F_1 = M_1 = B$ . In this simple case, observations on the phenotype of a child may lead to different situations:

- the child is typed  $A$  and the allele  $A$  is not dominant. In this case the only possible genotype is  $A|A$  or  $M_0|F_0$ . This is encoded by the character **A** in MapMaker.
- the child is typed  $A$  and  $A$  is dominant. Then the set of possible genotypes is  $\{A|A, A|B, B|A\}$ , i.e.,  $\{F_0|M_0, F_0|M_1, F_1|M_0\}$ . This is encoded by the character **D** in MapMaker.
- the child is typed  $B$  and the allele  $B$  is not dominant. In this case the only possible genotype is  $B|B$  or  $M_1|F_1$ . This is encoded by the character **B** in MapMaker.
- the child is typed  $B$  and  $B$  is dominant. Then the set of possible genotypes is  $\{A|B, B|A, B|B\}$ , i.e.,  $\{F_0|M_1, F_1|M_0, F_1, M_1\}$ . This is encoded by the character **C** in MapMaker.
- the child is typed  $AB$  (the marker is codominant) then the set of possible genotypes is  $\{A|B, B|A\}$ , i.e.,  $\{F_0|M_1, F_1|M_0\}$ . This is encoded by the character **H** in MapMaker.
- the child is untyped at this locus. The set of possible genotypes includes all possible genotypes i.e.  $\{F_0|M_0, F_0|M_1, F_1|M_0, F_1, M_1\}$ . This is encoded by the character **-** in MapMaker.

In order to be able to cope with all phases known situations, including cases where one parent is homozygous, when 3 or 4 different alleles are present, Carthagène actually enables the user to express any subset of the 4 different possibilities. In order to do so, these 4 possibilities are associated with a number:

- genotype  $F_0|M_0$  is associated with 1
- genotype  $F_0|M_1$  is associated with 2
- genotype  $F_1|M_0$  is associated with 4
- genotype  $F_1|M_1$  is associated with 8

and the user will be able to tell Carthagène which set of genotype is actually possible at a given locus by:

- adding up the numbers associated with each possible genotypes at the locus given the observations
- converting this number to hexadecimal (base 16 where one counts 1, 2, 3, 4, 5, 6, 7, 8, 9, a, b, c, d, e, f).

The following tables recapitulates all possible codes from 1 to f and the corresponding set of possible genotypes at the locus.

Notation	Synonym	Possible Genotypes
1	A	$F_0 M_0$
2		$F_0 M_1$
3		$F_0 M_0, F_0 M_1$
4		$F_1 M_0$
5		$F_0 M_0, F_1 M_0$
6	H	$F_0 M_1, F_1 M_0$
7	D	$F_0 M_0, F_0 M_1, F_1 M_0$
8	B	$F_1 M_1$
9		$F_0 M_0, F_1 M_1$
a		$F_0 M_1, F_1 M_1$
b		$F_0 M_0, F_0 M_1, F_1 M_1$
c		$F_1 M_0, F_1 M_1$
d		$F_0 M_0, F_1 M_0, F_1 M_1$
e	C	$F_0 M_1, F_1 M_0, F_1 M_1$
f	-	$F_0 M_0, F_0 M_1, F_1 M_0, F_1 M_1$

Here is an example of a small outbred dataset:

```
data type f2 intercross
40 5 0 0
*M1 111882228821414212414281812248128422488
*M2 141882228821414212414281882248128422488
*M3 4418828288821414242414281881148122422488
*M4 4412288228411814211444881884248222124488
*M5 8412288224412814811484881281848822184188
```

Let see how this can be used in some practical phase-known outbred situations according to the segregation ratio of the marker at the current locus.

**Segregation ratio 1:2:1** This is the usual case in F2 intercross with codominance. In this case, the parents  $F_0|F_1$  and  $M_0|M_1$  are such that typically  $F_0 = M_0 = A$  and  $F_1 = M_1 = B$  and  $AB$  codominate. The usual observations on the child are either phenotype  $A$ ,  $B$  or  $AB$ . this lead to the following encoding:

- $A$ : The only possible genotype is  $A|A = M_0|F_0$ : this is coded by 1 (the synonym A used in MapMaker can also be used).
- $B$ : The only possible genotype is  $B|B = M_1|F_1$ : this is coded by 8 (the synonym B in MapMaker can also be used).
- $AB$ : The only possible genotypes are  $A|B = M_0|F_1$  and  $B|A = M_1|F_0$ : this is coded by 6=4+2. The synonym H used in MapMaker can also be used.

When missing data occurs, it is still possible to give partial information to Carthagène. Eg., if the child is typed  $A$  but the other allele is not known. The child's genotype can be either  $A|A = M_0|F_0$  or  $A|B = M_0|F_1$  or  $B|A = M_1|F_0$ . This is encoded by the character  $7=1+2+4$  (synonym  $D$ )

The character  $e = 14 = 8+4+2$  (synonym  $C$ ) encodes a situation where the child has been typed  $B$  but the other allele is not known. In this case, the child's genotype can be  $B|B = F_1|M_1$  or  $A|B = F_0|M_1$  or  $B|A = F_1|M_0$ .

**Segregation ratio 3:1** This type of segregation ratio occurs when dominance appears. Imagine  $A$  dominates  $B$ , then it is impossible to distinguish between  $A|A$ ,  $A|B$  and  $B|A$ . Precisely, if the child is typed  $B$ , then the character 8 (or the synonym  $B$  of MapMaker) will be used. Else the character  $7 = 1+2+4$  (or the synonym  $D$  of MapMaker) will be used to represent the fact that we simply know that the child genotype is either  $A|A = F_0|M_0$ ,  $A|B = F_0|M_1$  or  $B|A = F_1|M_0$ .

Conversely, if  $B$  dominates  $A$ , the code 1 (resp.  $e$ ) will be used if the child is typed  $A$  (resp.  $B$ ). The respective synonyms  $A$  and  $C$  of MapMaker can also be used.

**Segregation ratio 1:1:1:1** This occurs when different alleles appear in the father and in the mother. For example in  $A|B \times C|D$ . In this case the child is either  $A|C$  or  $A|D$  or  $B|C$  or  $B|D$  and the corresponding codes are respectively 1 (or  $A$ ), 2, 4 and 8 (or  $B$ ).

When some data is missing, it is still possible to give information to Carthagène. Imagine for example that the child is typed  $A$  then the second allele is unknown. Because we have 4 different alleles, we know for sure that the first allele of the children is  $A$ . Therefore, the only possible genotypes are  $A|C$  (code 1) or  $A|D$  (code 2) and the corresponding code is  $3 = 1+2$ .

Imagine that instead of having 4 alleles, we have 3 alleles in  $A|B \times A|C$ . Then children may be  $A|A$ ,  $A|C$ ,  $B|A$  or  $B|C$  i.e., there is still a 1:1:1:1 segregation ratio. If again the children is just typed  $A$  then there is more indetermination at hand: the child may be either  $A|A$  (code 1),  $A|C$  (2) or  $B|A$  (code 4). In this case, the corresponding code is  $7 = 1+2+4$  (or the synonym  $D$ ).

**Segregation ratio 1:1** Imagine the second parent is homozygous at current locus i.e., we cross  $A|B$  with  $C|C$  (a backcross like situation), then the children genotypes may either be  $A|C$  or  $B|C$ . If we observe  $A|C$  (or  $A$  simply), it is not known where does the  $C$  come from i.e., the children may be  $A|C_0$  or  $A|C_1$ . This case is encoded by  $3 = 1+2$ . This is the sum of 1 and 2 which corresponds to the two possible cases:  $A|C$  with  $C$  coming from one grand-parent (code 1) or the other (code 2).

Similarly, if we observe  $B$ , then we know that the first allele is  $B$ , the second is  $C$  but we don't know where this allele comes from. The code will be  $c = 12 = 4+8$ .

If the homozygosity appears on the first parent ( $A|A \times B|C$ ) instead of the second one and if we observe  $B$  we get the code 5, the sum of 1 and 4 corresponding to the fact that the origin of the first allele is unknown. If we observe  $C$ , we get the code  $a$  which in hexadecimal corresponds to 10 which is the sum of 8 and 2.

## 2.1.2 Radiated Hybrid data sets

CAR<sub>H</sub>AGENE can handle both haploid and diploid radiated hybrid panels data using the so-called "equal retention model" [LBLC95]. CAR<sub>H</sub>AGENE uses a specific boosted EM [SCBM01] algorithm for handling *haploid* data. This algorithm may run one or two orders of magnitude faster than a standard EM algorithm without any loss of precision. We therefore strongly recommend you to use the haploid model for all RH data and to shift to the diploid model only for final estimation of distances.

Depending of the ploidy of the model you intend to use (haploid or diploid), the first header line of the dataset should be respectively set to:

```
data type radiated hybrid
```

or

data type radiated hybrid diploid

The character used to encode RH data are respectively:

- A for missing (Absent) marker.
- H for present (Here) marker.
- – for unknowns (eg. inconsistent typing when double typing is performed)

### 2.1.3 Constraints data sets

In some cases, you may want to incorporate ordering information that comes from another source of information (already published maps...) for which you don't have the data. CAR<sub>H</sub>TAGENE can try to take advantage of such information using so called "triplet constraints". A triplet constraint is defined by a triple of markers ( $m_1, m_2, m_3$ ) and a loglikelihood penalty  $p$  (expressed in base 10 logarithm). The "semantics" of such a triplet constraint is that any marker ordering inconsistent with the triplet ordering (i.e., an order that places  $m_2$  outside of the  $m_1 - m_3$  interval) will see its loglikelihood penalized by the amount  $p$ . Use this facility with extreme precaution since it breaks the good property of the maximum likelihood criterion used by CAR<sub>H</sub>TAGENE. The most obvious and reasonable use of this facility is to answer a question such as: is there a map that places the three markers as indicated in the triplet and whose loglikelihood is not worse than the loglikelihood of an optimal map by more than  $p$ .

A constraint dataset is simple composed by a set of such triplet constraints after a single header line:

data type constraint

A triplet constraint is simply written by putting the name of the 3 markers in the triplet in sequence followed by the penalty. An example of such a dataset is given below:

```
data type constraint
MS4 MS5 MS13 3.0
MS5 MS13 MS6 3.0
```

The markers mentioned in the triplet must be already known to CAR<sub>H</sub>TAGENE, i.e., one or several datasets which contain data about these markers must be already loaded.

### 2.1.4 Reference order data sets

In a comparative mapping approach, you want to take into account the knowledge of a completely sequenced genome for the purpose of mapping a genome of interest. In order to construct a reference order dataset, you have to find the orthologous relationships between your markers associated to genes and the genes in the sequenced genome. This can be obtained by sequence alignment reciprocal best hits.

The first header line of the dataset should be set to:

data type order

The second header line of the dataset indicates the number of orthologous markers followed by a zero. The remaining lines contain the **ordered** list of markers for each chromosome segment in the reference genome. Each line begins with a star character (\*) followed by the name of a marker and the position in basepairs of the marker in the chromosome, except for the first and last markers of each segment where the star character is replaced by the chromosome number. This number should be a positive integer between 1



and 9999. Notice that it is not possible to express singleton markers (i.e. a segment with only one marker). The basepair positions are needed by the graphical comparative mapping view only (see `paretoplotg`). This information is not used during the comparative mapping process.

The following is an example with 7 orthologous markers on two chromosomes (chr02 and chr07) in the reference genome.

```
data type order
7 0
2 UniSTS208788 7059292
* UniSTS180373 9019692
2 UniSTS160192 10214792
7 UniSTS160197 106361623
* UniSTS165815 106779006
* UniSTS180382 106822847
7 UniSTS180378 107120936
```

## 2.2 Loading and Merging data sets

To load a new dataset in `CARTAGENE`, the only command is the `dsload` command which must be followed by the name of the file to load. The dataset loaded will get a numerical id (reported when the dataset is loaded and which can be requested later using the `dsinfo` command).

To do multiple populations mapping, two merging commands can be used. Each of these commands takes as arguments the numerical id of the 2 datasets merged (if you want to merge more than 2 datasets together, simply use the commands repeatedly).

- `mergen`: assumes that the markers order and the distance/recombination ratios are the same in the two datasets merged. This command cannot be used to merge radiated hybrid data with genetic data (for obvious reasons) and also cannot merge RIL self/sib data with other genetic data (for mathematical reasons). On such datasets, a single consensus map is reported by all mapping commands.
- `mergor`: assumes only that the markers order is the same in the two populations merged. Population specific distances will be estimated. Any pair of types of dataset can be merged by this command. On such dataset, two maps are reported by all mapping commands. When few markers are common to the merged datasets, many equivalent maps may populate the heap and limit the efficiency of the `buildfw` command. See the `heapequiset` command.

All mapping/map validating commands applied to merged datasets still compute exact multipoint maximum likelihood.

These two commands can be used together and repeatedly. Imagine for example that you have 2 radiated hybrid panels with the same irradiation level along with 2 genetic datasets available. You can “mergen” the 2 RH datasets together (assuming that the same irradiation level will lead to the same distances) and also “mergen” the 2 genetic datasets. This will give you two merged datasets which can be again merged using the `mergor` command. This gives a single dataset that merges all 4 datasets. All mapping commands on this dataset will report two maps: one RH consensus map and one genetic consensus map with the guarantee that they use a consistent markers order.

### 2.2.1 `dsload`

Loads a data-set from a file.

**Synopsis:** The `dsload` command is invoked either as:

- `dsload Options`
- `dsload FilePath`

**Description:** The `dsload` command loads the data-set from the file whose path is indicated in the argument *FilePath*.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *FilePath*: the path to a valid CarthaGene data-set.

**Returns:** a list summarizing some basic information on the data-set loaded:

- numerical Id of the data-set.
- type of the data-set.
- number of markers in the data-set.
- number of individuals/hybrids in the data-set.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> dsload Data/rh.cg  
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG>
```

**See also:**

- `dsinfo` (2.2.5)
- `dsget` (2.2.6)
- `dsmergor` (2.2.3)
- `dsmergen` (2.2.2)

### 2.2.2 dsmergen

Merges two data-sets in a consensus data-set, sharing order and distances.

**Synopsis:** The `dsmergen` command is invoked either as:

- `dsmergen Options`
- `dsmergen DsId1 DsId2`

**Description:** The `dsmergen` command merges two data-sets of compatible types in a single consensus data-set. If more than 2 data-sets need to be merged, this command must be called repeatedly. The consensus data-set built uses all the information available in the two data-sets for eg. maximum likelihood multipoint estimations. Only data-sets of “compatible” types can be merged using this merging operator:

- radiated hybrid data can only be merged with other RH data (and this assumes a similar level of irradiation)
- f2 (backcross/intercross) and outbred data can all be merged together using this operator,
- RIL data of a given type (Sib or Self) can only be merged with data-sets of the same type (Sib/Self respectively).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *DsId1 DsId2*: the numerical Id of the two data sets to merge.

**Returns:** a list summarizing some basic information on the merged data-set:

- numerical Id of the data-set.
- type of the data-set (i.e., merged genetic)
- number of markers in the data-set.
- number of individuals/hybrids in the data-set.

The number of markers is usually strictly less than the number of markers in each of the merged data-set (identical markers are detected by their identical name).

**Example:**

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg
```

```
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/bc1.cg
{2 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsmergen 1 2
{3 merged genetic 20 416}
CG> mrkinfinfo
```

Markers :

-----:

Num	Names :	Sets	Merges
1	MS1 :	1 2 3	
2	MS2 :	1 2 3	
3	MS3 :	1 2 3	
4	MS4 :	1 2 3	
5	MS5 :	1 2 3	
6	MS6 :	1 2 3	
7	MS7 :	1 2 3	
8	MS8 :	1 2 3	
9	MS9 :	1 2 3	
10	MS10 :	1 2 3	
11	MS11 :	1 2 3	
12	MS12 :	1 2 3	
13	MS13 :	1 2 3	
14	MS14 :	1 2 3	
15	MS15 :	1 2 3	
16	MS16 :	1 2 3	
17	MS17 :	1 2 3	
18	MS18 :	1 2 3	
19	MS19 :	1 2 3	
20	MS20 :	1 2 3	

#### See also:

- dsmergor (2.2.3)
- dsload (2.2.1)
- dsinfo (2.2.5)
- dsget (2.2.6)

### 2.2.3 dsmergor

Merges two data-sets in a consensus data-set, sharing order but with separate parameter estimations (data-set specific recombination/breakage/retention ratio).

**Synopsis:** The dsmergor command is invoked either as:

- dsmergor *Options*
- dsmergor *DsId1 DsId2*

**Description:** The `dsmergor` command merges two data-sets of compatible types in a single data-set for which an overall maximum likelihood marker ordering is sought. If more than 2 data-sets need to be merged, this command must be called repeatedly. The merged data-set built uses all the information available in the two data-sets but independent maximum likelihood multipoint parameter estimations are performed on each data-set. This can be used to eg. determine sex-specific recombination ratio.

There is no restriction on the type of data-sets that can be merged using this operator (including merging of radiated hybrid and genetic recombination data).

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *DsId1 DsId2*: the numerical Id of the two data sets to merge.

**Returns:** a list summarizing some basic information on the merged data-set:

- numerical Id of the data-set.
- type of the data-set (i.e., merged by order)
- number of markers in the data-set.
- number of individuals/hybrids in the data-set.

The number of markers is usually strictly less than the number of markers in each of the merged data-set (identical markers are detected by their identical name).

#### Example:

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> dsload Data/rh.cg  
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> dsmergor 1 2  
{3 merged by order 59 326}
```

#### See also:

- `dsmergen` (2.2.2)
- `dsload` (2.2.1)
- `dsinfo` (2.2.5)
- `dsget` (2.2.6)

## 2.2.4 heapequiset

Activates or desactivates the detection of “equivalent” orders on datasets merged using the `dsmergor` command.

**Synopsis:** The `heapequiset` command is invoked either as:

- `heapequiset Options`
- `heapequiset on/off flag`

**Description:** When two datasets are merged, it is often the case that the two data sets only share few markers. When the two such datasets are merged using `dsmergor`, many different orders correspond to equivalent situations on the two datasets and they will get the same log-likelihood. Imagine for example that the dataset 1 is informative on markers *A*, *B*, *D* and *E* and that the dataset 2 is informative on markers *A*, *C* and *E*. Then the orders *ABCDE*, *ACBDE* and *ABDCE* are equivalent and will get the same loglikelihood since they both correspond to the two same orders: *ABDE* on dataset one and *ACE* on the dataset 2.

This phenomenon will populate the heap with many equivalent maps and also severely limit the efficacy of the `buildfw` process we uses the heap structure internally to detect if two orders with close enough likelihoods exist. At some point, It may be impossible to insert a marker in the framework map because equivalent orders (therefore with the same likelihood) exist in the heap. To avoid this, activate the `heapequiset` command. It is important to mention that as soon as the mode is activated, “equivalent” orders are expunged from the heap. The command is still in alpha stage.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *level*: the on/off flag (0 for off or 1 for on).

**Returns:** nothing.

**Example:**

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
# we load and merge two datasets
```

```
CG> dsload Data/bc.cg
```

```
...
```

```
CG> dsload Data/rh.cg
```

```
...
```

```
CG> dsmergor 1 2
```

```
...
```

```
# we evaluate two different but equivalent orders
```

```

CG> mrkselset {17 29 30 18 39 19}

CG> sem

Map -1 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17      MS18      MS19
  2 : MS17 G9 G10      G19 MS19

# we move the marker 18 which is only defined in the first dataset
CG> mrkselset {17 29 18 30 39 19}

CG> sem

Map -1 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17      MS18      MS19
  2 : MS17 G9      G10 G19 MS19

# the two orders have entered the heap
CG> heaprint

Map 0 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17      MS18      MS19
  2 : MS17 G9 G10      G19 MS19

Map 1 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17      MS18      MS19
  2 : MS17 G9      G10 G19 MS19

# we now activate the detection of equivalent orders
CG> heapequiset 1

# the equivalent order is expunged
CG> heaprint

Map 0 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17      MS18      MS19
  2 : MS17 G9 G10      G19 MS19

# we evaluate a third equivalent order
CG> mrkselset {17 18 29 30 39 19}

CG> sem

Map -1 : log10-likelihood = -151.70
-----:
Set : Marker List ...
  1 : MS17 MS18      MS19
  2 : MS17      G9 G10 G19 MS19

```

```
# it did not entered the heap
CG> heapprint

Map  0 : log10-likelihood =  -151.70
-----:
Set  : Marker List ...
      1 : MS17          MS18          MS19
      2 : MS17 G9 G10          G19 MS19

CG>
```

**See also:**

- `dsmergor` (2.2.3)

## 2.2.5 `dsinfo`

Displays a summary of information on all the data-sets that are currently available.

**Synopsis:** The `dsinfo` command is invoked either as:

- `dsinfo Options`
- `dsinfo`

**Description:** The `dsinfo` command display a table of information on all the data-sets currently available in the software. For each data-set, a line summarizes:

- the numerical Id of the data-set.
- the type of the data-set.
- the number of markers that appear in the data-set.
- the number of individuals (hybrids) that appear in the data-set.
- the number of order constraints in the data-set.
- if the data-set is a merged data-set, which data-set it merges.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.



### Example:

```
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Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/rh.cg
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 59 326}
CG> dsinfo

Data Sets :
-----:
ID      Data Type      markers individuals      filename constraints...
1      f2 backcross      20          208          bc.cg
2      haploid RH      53          118          rh.cg
3      merged by order  59          326          ...
```

### See also:

- `dsget` (2.2.6)
- `dsload` (2.2.1)

## 2.2.6 dsget

Displays a summary of all the data-sets that are currently loaded.

**Synopsis:** The `dsget` command is invoked either as:

- `dsget Options`
- `dsget`

**Description:** The `dsget` command returns a list of descriptions of all the data-sets that have been loaded since the beginning of the session. For each data-set, the numerical id of the data-set, its type, the number of markers that appears in it and the numbers of individuals (hybrid) typed in it are reported in a list.

### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** a list of list of information on the available data-sets.

### Example:

```
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```

```
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```

Type 'help' for help.

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> dsload Data/rh.cg  
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> dsmergor 1 2  
{3 merged by order 59 326}  
CG> dsget  
{1 "f2 backcross" /home/ubuntu/carthagene/build/linux64/Release/doc/user/ex...
```

### See also:

- dsinfo (2.2.5)
- dsload (2.2.1)
- mrkinfo (2.3.5)

## 2.3 Markers, linkage groups and 2-points estimations

For a given dataset, CAR<sub>T</sub>HAGENE performs all 2-points LOD calculations when the data set is loaded. This explains why loading large datasets can be (relatively) slow for expensive pedigree (eg. outbreds). All 2-points information can be requested using the `mrklod2p`, `mrkfr2p` and `mrkdist2p` commands. The `mrkdouble` (and `mrkdoubleget` which returns a Tcl list of compatible markers) command reports all pairs of markers that have compatible typing (i.e., markers which may be identical) along with their 2-points LOD. This can occur in two cases:

- the two markers have never been typed on a single common individual. These 2 markers should not be merged and this is clearly indicated by the fact that their 2-points LOD is equal to 0.
- the two markers have been typed on a possibly large number of individuals and no sure recombination (or breakage for RH) exists between the two markers. The 2 markers can be merged and this is indicated by the usually strong 2-points LOD between the 2 markers.

When two markers are merged using the `mrkmerge` command, no information is lost. All the information is merged in the first marker and the second marker is deselected. The number of markers to map is lowered and the information stronger. This is always a good thing. Command `mrkmerges` merges all pairs of compatible markers detected by `mrkdouble` automatically.

Several other commands can be used to get information about markers. The most useful ones are probably the commands that can convert marker names to their numerical Id (`mrkid` and `mrkids` commands) and vice-versa (`mrkname` and `mrknames` commands).

The 2-points estimations are the basis of the linkage group computation process performed using the `group` command. This command puts in the same linkage group any two markers such that:

- their 2-points LOD is above a given threshold *and*
- their 2-points distance is below a given threshold.

The two conditions must be met together. Once groups are computed using this command, you can use a group using the `groupget` command.

If you have several datasets on the same markers (for instance, two RH panels with different resolutions), you can further eliminate markers which are poorly linked in at least one dataset to the rest of the markers in the selected linkage group. See the command `multigroup`.

### 2.3.1 `mrkallget`

Get the list of all the numerical ids of all the markers currently known in the current data-set.

**Synopsis:** The `mrkallget` command is invoked as either one of :

- `mrkallget Options`
- `mrkallget`

**Description:** returns the list of all the numerical Ids of all the markers known to the system. This can be typically used as an argument to `mrkselset`.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns :** The list of all the numerical Ids of all the markers known.

**Example :**

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/rh.cg
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> mrkallget
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29\
 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 5\
5 56 57 58 59
# to select all markers
CG> mrkselset [mrkallget]
```

**See also:**

- mrkselset (2.3.14)
- mrkselget (2.3.13)

## 2.3.2 mrkdist2p

Displays the two-points distance matrix using the specified mapping function (h/k).

**Synopsis:** The mrkdist2p command is invoked as either one of :

- mrkdist2p *Options*
- mrkdist2p *Unit*

**Description:** mrkdist2p prints the two-points distance estimation using either Haldane (h) or Kosambi (k) mapping function. For radiated hybrid data, Ray distances are always used, independently of the argument (which must nevertheless be given).

**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *Unit*: may either h (Haldane) or k (Kosambi).

**Returns:** nothing.

**Example:**

```
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Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> group 0.1 9

Linkage Groups :
-----;
LOD threshold=9.00
Distance threshold=10.00:

Group ID : Marker ID List ...
  1 : 17 19 20 18
  2 : 14
  3 : 11 13 12 16 15
  4 : 10
```

```

        5 : 2 4 3 7 6 5 9 8
        6 : 1
6
CG> mrkselset [groupget 3]

CG> mrkdist2p k

Print two points distance matrices of the loci selection :
-----:

Data Set Number 1 :
      MS11  MS13  MS12  MS16  MS15
-----
MS11 |----- 7.8  10.3  22.5  16.2
MS13 | 7.8 ----- 0.0  14.5  15.5
MS12 | 10.3  0.0 ----- 8.3   3.5
MS16 | 22.5  14.5  8.3 ----- 4.9
MS15 | 16.2  15.5  3.5   4.9 -----

```

**See also:**

- `mrklod2p` (2.3.7)
- `mrkfr2p` (2.3.3)

### 2.3.3 `mrkfr2p`

Displays the two-points recombination (or breakage) ratio matrix of the current loci selection.

**Synopsis :** The `mrkfr2p` command is invoked either as:

- `mrkfr2p Options`
- `mrkfr2p`

**Description :** `mrkfr2p` prints the two-points recombination (or breakage) ratio for all pairs of loci in the current list of selected loci.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

### Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> group 0.1 9

Linkage Groups :
-----:
LOD threshold=9.00
Distance threshold=10.00:

Group ID : Marker ID List ...
  1 : 17 19 20 18
  2 : 14
  3 : 11 13 12 16 15
  4 : 10
  5 : 2 4 3 7 6 5 9 8
  6 : 1
6
CG> mrkselset [groupget 3]

CG> mrkfr2p

Print two-points recombination-fraction matrices of the locus selection :
-----:

      MS11  MS13  MS12  MS16  MS15
-----
MS11 |-----0.077 0.101 0.211 0.156
MS13 |0.077 -----0.000 0.141 0.150
MS12 |0.101 0.000 -----0.082 0.035
MS16 |0.211 0.141 0.082 -----0.049
MS15 |0.156 0.150 0.035 0.049 -----
```

### See also:

- mrklod2p (2.3.7)
- mrkdist2p (2.3.2)

### 2.3.4 mrkid

Returns the numerical Id of the marker of the given name.

**Synopsis:** The `mrkid` command is invoked either as:

- `mrkid Options`
- `mrkid name`
- `mrkids names` or list of names

**Description:** the command returns the unique numerical id of the marker whose name is given as an argument. This numerical id is used in several other commands. The variant `mrkids` can take as argument several names or a list of names and returns a list of numerical Ids.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *name*: the name of the marker as it appears in the dataset it has been loaded from.

**Returns:** the numerical id of the marker.

**Example:**

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> mrkid MS9  
9  
CG> mrkids MS9 MS10  
9 10  
CG> mrkmerge [mrkid MS9] [mrkid MS10]  
Markers 9 and 10 merged in 9.  
  
#Markers 9 and 10 merged in 9.
```

**See also:**

- `mrkinfo` (2.3.5)

## 2.3.5 `mrkinfo`

Displays basic information on all known markers.

**Synopsis:** The `mrkinfo` command is invoked either as:

- `mrkinfo Options`
- `mrkinfo`

**Description:** For each marker known to the system, the command displays its numerical Id, its name, the numerical Id of all the data-sets in which the marker is defined and also if the marker has been merged (see `mrkmerge`, section 2.3.9) with another marker: when the marker  $i$  has been merged with the marker  $j$  the result of the merging being stored in  $i$ , then the information on  $i$  mentions  $j$ .

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> dsload Data/rh.cg  
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> dsmergor 1 2  
{3 merged by order 59 326}  
CG> mrkinfo
```

Markers :

-----:

Num	Names	:	Sets	Merges
1	MS1	:	1 2	3
2	MS2	:	1 2	3
3	MS3	:	1 2	3
4	MS4	:	1 2	3
5	MS5	:	1 2	3
6	MS6	:	1 2	3
7	MS7	:	1 2	3
8	MS8	:	1 2	3
9	MS9	:	1 2	3
10	MS10	:	1	3
11	MS11	:	1	3
12	MS12	:	1	3
13	MS13	:	1 2	3
14	MS14	:	1	3
15	MS15	:	1 2	3



16	MS16 :	1		3
17	MS17 :	1	2	3
18	MS18 :	1		3
19	MS19 :	1	2	3
20	MS20 :	1	2	3
21	G1 :		2	3
22	G2 :		2	3
23	G3 :		2	3
24	G4 :		2	3
25	G5 :		2	3
26	G6 :		2	3
27	G7 :		2	3
28	G8 :		2	3
29	G9 :		2	3
30	G10 :		2	3
31	G11 :		2	3
32	G12 :		2	3
33	G13 :		2	3
34	G14 :		2	3
35	G15 :		2	3
36	G16 :		2	3
37	G17 :		2	3
38	G18 :		2	3
39	G19 :		2	3
40	G20 :		2	3
41	G21 :		2	3
42	G22 :		2	3
43	G23 :		2	3
44	G24 :		2	3
45	G25 :		2	3
46	G26 :		2	3
47	G27 :		2	3
48	G28 :		2	3
49	G29 :		2	3
50	G30 :		2	3
51	G31 :		2	3
52	G32 :		2	3
53	G33 :		2	3
54	G34 :		2	3
55	G35 :		2	3
56	G36 :		2	3
57	G37 :		2	3
58	G39 :		2	3
59	G40 :		2	3

**See also :**

- `mrkmerge` (2.3.9)
- `dsinfo` (2.2.5)

### 2.3.6 `mrklast`

Returns the numerical Id of the last marker known.

**Synopsis :** The `mrklast` command is invoked either as:

- `mrklast Options`
- `mrklast`

**Description:** returns the numerical Id of the last marker loaded i.e., the largest marker numerical Id currently used. This can be useful to process all markers in a Tcl macro.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** the numerical Id of the last marker known.

**Example:**

```
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```

```
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```

```
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```

Type 'help' for help.

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> dsload Data/rh.cg  
{2 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> mrklast  
59
```

**See also:**

- `mrkallget (2.3.1)`

### 2.3.7 `mrklod2p`

Displays the two-points LOD matrix for all currently active markers.

**Synopsis :** The `mrklod2p` command is invoked either as:

- `mrklod2p Options`
- `mrklod2p`

**Description:** `mrklod2p` prints the two-points LOD for all pairs of loci in the list of currently selected loci.

## Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.

## Example:

```
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```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
# we first load a data set
```

```
CG> dsload Data/bc.cg
```

```
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
```

```
# and select some markers in it
```

```
CG> mrkselset {11 12 13 14 15 16 17 18 19 20}
```

```
# then ask for the 2pt LOD matrix
```

```
CG> mrklod2p
```

	11	12	13	14	15	16	17	18	19	20
	MS11	MS12	MS13	MS14	MS15	MS16	MS17	MS18	MS19	MS20
MS11	-----	10.9	11.9	3.6	3.6	5.5	0.1	0.4	0.6	0.5
MS12	10.9	-----	18.7	3.6	26.5	25.9	2.1	4.6	4.2	4.3
MS13	11.9	18.7	-----	6.0	4.7	9.7	0.9	0.7	0.6	0.7
MS14	3.6	3.6	6.0	-----	0.0	3.6	1.5	0.0	0.5	0.7
MS15	3.6	26.5	4.7	0.0	-----	26.6	3.8	6.9	6.9	6.2
MS16	5.5	25.9	9.7	3.6	26.6	-----	6.3	10.3	8.2	7.7
MS17	0.1	2.1	0.9	1.5	3.8	6.3	-----	16.0	14.1	11.3
MS18	0.4	4.6	0.7	0.0	6.9	10.3	16.0	-----	27.1	22.9
MS19	0.6	4.2	0.6	0.5	6.9	8.2	14.1	27.1	-----	34.8
MS20	0.5	4.3	0.7	0.7	6.2	7.7	11.3	22.9	34.8	-----

## See also:

- mrkselset (2.3.14)
- mrkmerge (2.3.9)

## 2.3.8 mrkdouble

Analyzes possible equivalent haplotypes (pairs of markers whose genotyping are “compatible” and could therefore be merged) in the current markers selection.

**Synopsis :** The mrkdouble command is invoked either as:

- mrkdouble *Options*
- mrkdouble

**Description:** `mrkdouble` analyzes, for each pair of marker, if the two markers have compatible genotyping (i.e. if the genotyping of the two markers can be assumed to be the same w/o any inconsistency). When two markers are “compatible”, their two-points LOD are presented to decide to merge (or not) the two markers (compatible markers with null LOD are simply markers that are compatible because they do not share any information and should therefore not be merged).

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Example:**

```
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Type 'help' for help.

# we first load a data set
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
# and select some markers in it
CG> mrkselset {11 12 13 14 15 16 17 18 19 20}

# this identifies pairs of markers that can be merged
CG> mrkdouble

Possible double markers:

MS11 = MS14           [3.6]
MS12 = MS13           [18.7]
MS12 = MS14           [3.6]
MS13 = MS14           [6.0]
MS14 = MS16           [3.6]
MS14 = MS17           [1.5]
MS17 = MS18           [16.0]
```

**See also:**

- `mrkmerges` (2.3.10)
- `mrkmerge` (2.3.9)
- `mrkselset` (2.3.14)
- `mrkmerge` (2.3.7)

## 2.3.9 `mrkmerge`

Merges two markers in one.

**Synopsis :** The `mrkmerge` command is invoked either as:

- `mrkmerge Options`
- `mrkmerge mrkid1 mrkid2`

**Description :** The command is used to merge two markers whose observed genotypes on all individuals are compatible with each other (closely related markers for which no recombination has been observed). Such “double markers” are identified automatically using the command `mrklod2p`.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *mrkid1 mrkid2*: the observations on marker number *mrkid1* and marker *mrkid2* are merged in the marker *mrkid1* and the marker *mrkid2* is removed from the set of selected markers.

**Returns :** Nothing

**Example :**

```
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```

```
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```

```
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```

```
Type 'help' for help.
```

```
# we first load a data set  
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
# and ask for markers that can be merged  
CG> mrkdouble
```

```
Possible double markers:
```

MS9 = MS10	[7.2]
MS9 = MS14	[3.6]
MS10 = MS11	[3.6]
MS11 = MS14	[3.6]
MS12 = MS13	[18.7]
MS12 = MS14	[3.6]
MS13 = MS14	[6.0]
MS14 = MS16	[3.6]
MS14 = MS17	[1.5]
MS17 = MS18	[16.0]

```
# then merge markers 9 and 10 in 9.  
CG> mrkmerge [mrkid MS9] [mrkid MS10]  
Markers 9 and 10 merged in 9.
```

**See also :**

- `mrkmerges` (2.3.10)
- `mrklod2p` (2.3.7)

### 2.3.10 **mrkmerges**

Merges all pairs of compatible markers detected by `mrkdouble`.

**Synopsis :** The `mrkmerges` command is invoked either as:

- `mrkmerges Options`
- `mrkmerges`

**Description :** The command is used to merge all pairs of markers whose observed genotypes on all individuals are compatible with each other (closely related markers for which no recombination/breakage has been observed) and at least one individual is genotyped for the two markers (i.e. LOD 2pt between the two markers is strictly greater than 0). Notice that marker1 can be compatible with marker2 and marker3, but after merging marker1 with marker2, the resulting genotyping vector corresponding to this group of two markers may be no more compatible with the one of marker3. `mrkmerges` checks this case, possibly reporting that two markers are no more compatibles.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- : without parameters, merges all pairs of compatible markers.

**Returns :** Nothing

**Example :**

```
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```

```
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```

```
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```

```
Type 'help' for help.
```

```
# we first load a data set  
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
# and ask for markers that can be merged  
CG> mrkdouble
```

Possible double markers:

```
MS9 = MS10 [7.2]
```

MS9 = MS14	[3.6]
MS10 = MS11	[3.6]
MS11 = MS14	[3.6]
MS12 = MS13	[18.7]
MS12 = MS14	[3.6]
MS13 = MS14	[6.0]
MS14 = MS16	[3.6]
MS14 = MS17	[1.5]
MS17 = MS18	[16.0]

```
# then merge all compatible markers
CG> mrkmerges
Markers 9 and 10 merged in 9.
The two markers are incompatibles.
The two markers are incompatibles.
Markers 12 and 13 merged in 12.
Markers 11 and 14 merged in 11.
The two markers are incompatibles.
The two markers are incompatibles.
The two markers are incompatibles.
Markers 17 and 18 merged in 17.
The two markers are incompatibles.
```

#### See also :

- `mrkdouble` (2.3.8)
- `mrkmerge` (2.3.9)

### 2.3.11 `mrkmerget`

Retrieves the sets of markers that have been merged together.

**Synopsis :** The `mrkmerget` command is invoked either as:

- `mrkmerget Options`

**Description:** The command is used to retrieve the sets of markers that have been merged together.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns :** a list of list of markers id. The first marker of a sublist represent the others.

### Example :

```
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Type 'help' for help.

# we first load a data set
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
# and ask for markers that can be merged
CG> mrkdouble

Possible double markers:

          MS9 = MS10          [7.2]
          MS9 = MS14          [3.6]
          MS10 = MS11         [3.6]
          MS11 = MS14         [3.6]
          MS12 = MS13         [18.7]
          MS12 = MS14         [3.6]
          MS13 = MS14         [6.0]
          MS14 = MS16         [3.6]
          MS14 = MS17         [1.5]
          MS17 = MS18         [16.0]

# then merge markers 9 and 10 in 9.
CG> mrkmerge [mrkid MS9] [mrkid MS10]
Markers 9 and 10 merged in 9.

#...
CG> mrkmerge [mrkid MS12] [mrkid MS13]
Markers 12 and 13 merged in 12.

CG> mrkmerge [mrkid MS12] [mrkid MS14]
Markers 12 and 14 merged in 12.

#retrive the information
CG> mrkmerget
{9 10 } {12 13 14 }
```

### See also:

- mrkmerge (2.3.9)

### 2.3.12 mrkname

Displays the name of the marker number *mrkid*.



**Synopsis :** The CarthaGene `mrkname` command is invoked as either one of :

- `mrkname Options`
- `mrkname mrkid`
- `mrknames mrkids` or a list of *mrkid*

**Description :** The commande `mrkname` displays the name of the marker whose number is *mrkid*. The `mrkids` commands takes as arguments several Ids or a list of Ids and return a list of marker names.

**Arguments :**

- *Options*: `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *mrkid*: the numerical id of the marker whose name will be displayed.

**Returns :** The name of the marker.

**Example :**

```
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```

```
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```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> mrkname 1  
MS1  
CG> mrknames 1 2 4 5  
MS1 MS2 MS4 MS5
```

**See also :**

- `mrkid` (2.3.4)
- `mrklast` (2.3.6)
- `mrkinfo` (2.3.5)
- `mrkselget` (2.3.13)

### 2.3.13 `mrkselget`

Returns the list of the numerical Id of all active markers.

**Synopsis:** The `mrkselget` command is invoked either as:

- `mrkselget Options`
- `mrkselget`

**Description:** the command returns the list of the numerical Ids of the active markers (see `mrkselset`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** the list of the numerical Id of all the active markers.

**Example:**

```
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```

```
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```

```
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```

Type 'help' for help.

```
CG> dsload Data/rh.cg  
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> group 0.3 3
```

```
Linkage Groups :  
-----:  
LOD threshold=3.00  
Distance threshold=30.00:
```

```
Group ID : Marker ID List ...  
1 : 52  
2 : 42 48 47 45 46 44 43  
3 : 41  
4 : 38  
5 : 37 39  
6 : 36 40  
7 : 35  
8 : 25  
9 : 22  
10 : 19 32 31 28 30 27 26 20 21  
11 : 13 14  
12 : 11 12  
13 : 10 15 16 18 17  
14 : 7  
15 : 6 51 8 53 50 9  
16 : 4 34 33 24 23 5  
17 : 3 29  
18 : 2 49  
19 : 1
```

```

19
CG> mrkselset [groupget 10]

CG> mrkselget
19 32 31 28 30 27 26 20 21
CG> mrknames [mrkselget]
G5 G18 G17 G14 G16 G13 G12 G6 G7

```

**See also:**

- mrkselset (2.3.14)
- mrkallget (2.3.1)

## 2.3.14 mrkselset

Changes the set and the default order of currently active markers.

**Synopsis:** The `mrkselset` command is invoked either as:

- `mrkselset Options`
- `mrkselset List of markers id`

**Description:** the command sets the list of currently active markers to the list of markers received as argument. The order of the markers in the list is used as the default order by some commands (such as `sem`).

If the set of the markers chosen differs from the previous list of active markers (available through `mrkselget`), then the current heap of maps becomes obsolete and is therefore emptied and reset.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *List of markers id*: a list of all the numerical ids of all the markers that will be active.

**Returns:** nothing.

**Example :**

```

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Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...

```

```

CG> group 0.3 3

Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=30.00:

Group ID : Marker ID List ...
  1 : 52
  2 : 42 48 47 45 46 44 43
  3 : 41
  4 : 38
  5 : 37 39
  6 : 36 40
  7 : 35
  8 : 25
  9 : 22
 10 : 19 32 31 28 30 27 26 20 21
 11 : 13 14
 12 : 11 12
 13 : 10 15 16 18 17
 14 : 7
 15 : 6 51 8 53 50 9
 16 : 4 34 33 24 23 5
 17 : 3 29
 18 : 2 49
 19 : 1
19
CG> mrkselset [groupget 10]

CG> sem

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
  1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

```

#### See also:

- `mrkselget` (2.3.13)
- `mrkallget` (2.3.1)
- `groupget` (2.3.19)

### 2.3.15 `mrkadd`

Inserts the marker of the given numerical Id at the end of the current marker selection.

**Synopsis:** The `mrkadd` command is invoked as:

- `mrkadd name`

**Description:** the command inserts the marker with the numerical id given as argument after the last marker in the current marker selection. An error is reported if the marker already appears in the list of selected markers.

**Arguments:**

- *name*: the numerical Id of the marker.

**Returns:** Nothing.

**Example:**

```
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Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> group 0.3 3

Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=30.00:

Group ID : Marker ID List ...
  1 : 52
  2 : 42 48 47 45 46 44 43
  3 : 41
  4 : 38
  5 : 37 39
  6 : 36 40
  7 : 35
  8 : 25
  9 : 22
 10 : 19 32 31 28 30 27 26 20 21
 11 : 13 14
 12 : 11 12
 13 : 10 15 16 18 17
 14 : 7
 15 : 6 51 8 53 50 9
 16 : 4 34 33 24 23 5
 17 : 3 29
 18 : 2 49
 19 : 1
19
CG> mrkselset [groupget 10]

CG> mrkselget
19 32 31 28 30 27 26 20 21
CG> mrkadd 7
```

```
CG> mrkselget
19 32 31 28 30 27 26 20 21 7
```

**See also:**

- `mrkid` (2.3.4)
- `mrkdel` (2.3.17)
- `mrkselget` (2.3.13)
- `mrkselset` (2.3.14)

### 2.3.16 `mrksub`

Removes the marker of the given numerical Id from the current marker selection.

**Synopsis:** The `mrksub` command is invoked as:

- `mrksub Id`

**Description:** the command removes the marker with the numerical Id given as argument from the current marker selection. No error is reported if the marker does not appear in the current list.

**Arguments:**

- *Id*: the numerical Id of the marker as it appears in the dataset it has been loaded from.

**Returns:** Nothing.

**Example:**

```
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```

```
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```

```
Type 'help' for help.
```

```
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> group 0.3 3
```

```
Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=30.00:
```

```
Group ID : Marker ID List ...
```

```

1 : 52
2 : 42 48 47 45 46 44 43
3 : 41
4 : 38
5 : 37 39
6 : 36 40
7 : 35
8 : 25
9 : 22
10 : 19 32 31 28 30 27 26 20 21
11 : 13 14
12 : 11 12
13 : 10 15 16 18 17
14 : 7
15 : 6 51 8 53 50 9
16 : 4 34 33 24 23 5
17 : 3 29
18 : 2 49
19 : 1
19
CG> mrkselset [groupget 10]

CG> mrkselget
19 32 31 28 30 27 26 20 21
CG> mrksub 20

CG> mrkselget
19 32 31 28 30 27 26 21

```

**See also:**

- `mrkid` (2.3.4)
- `mrkdel` (2.3.17)
- `mrkselget` (2.3.13)
- `mrkselset` (2.3.14)

## 2.3.17 `mrkdel`

Remove the marker of the given name from the current marker selection.

**Synopsis:** The `mrkdel` command is invoked as:

- `mrkdel name`

**Description:** the command removes the marker with the name given as argument from the current marker selection. No error is reported if the marker does not appear in the current list.

**Arguments:**

- *name*: the name of the marker as it appears in the dataset it has been loaded from.

**Returns:** Nothing.

**Example:**

```
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```

```
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```

```
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```

Type 'help' for help.

```
CG> dsload Data/rh.cg  
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> group 0.3 3
```

```
Linkage Groups :  
-----:  
LOD threshold=3.00  
Distance threshold=30.00:
```

```
Group ID : Marker ID List ...  
1 : 52  
2 : 42 48 47 45 46 44 43  
3 : 41  
4 : 38  
5 : 37 39  
6 : 36 40  
7 : 35  
8 : 25  
9 : 22  
10 : 19 32 31 28 30 27 26 20 21  
11 : 13 14  
12 : 11 12  
13 : 10 15 16 18 17  
14 : 7  
15 : 6 51 8 53 50 9  
16 : 4 34 33 24 23 5  
17 : 3 29  
18 : 2 49  
19 : 1
```

19

```
CG> mrkselset [groupget 10]
```

```
CG> mrknames [mrkselget]  
G5 G18 G17 G14 G16 G13 G12 G6 G7  
CG> mrkdel G6
```

```
CG> mrknames [mrkselget]  
G5 G18 G17 G14 G16 G13 G12 G7
```

**See also:**

- mrkname (2.3.12)
- mrksub (2.3.16)



- mrkselget (2.3.13)
- mrkselset (2.3.14)

### 2.3.18 group

Computes linkage groups in a data-set.

**Synopsis:** The `group` command is invoked as either:

- `group Options`
- `group Dist-Threshold LOD-Threshold`

**Description:** The `group` command computes cluster of markers, trying to identify linkage groups. The clustering is performed by putting in the same cluster any two markers such that their estimated two-points distance (using Haldane for genetic data) and their two-points LOD is respectively smaller than *Dist-Threshold* and larger than *LOD-Threshold*. This analysis is transitive in the sense that if there is reason to cluster together markers *A* and *B* on one side and markers *B* and *C* on another, then all three markers will be put together (whether there is evidence for or against putting *A* and *C* together). Parameters should be typically adjusted to get a number of linkage groups consistent with the number of chromosomes in the organism.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Dist-Threshold*: the maximum two-point distance (Haldane/Ray).
- *LOD-Threshold*: the minimum two-point LOD.

**Returns:** the number of linkage groups detected.

#### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh.cg  
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> group 0.5 3
```

```
Linkage Groups :  
-----:  
LOD threshold=3.00  
Distance threshold=50.00:
```

```

Group ID : Marker ID List ...
  1 : 13 35 14
  2 : 10 18 17 16 15 11 12
  3 : 7
  4 : 6 53 52 8 51 50 9
  5 : 4 34 33 24 23 5 25
  6 : 3 32 29 31 30 28 27 26 20 19 21 22
  7 : 2 49 48 47 46 45 44 43 42 38 37 40 39 36 41
  8 : 1
8
CG>

```

**See also:**

- `groupget` (2.3.19)

### 2.3.19 `groupget`

Returns the linkage group from its group number.

**Synopsis :** The CarthaGene `groupget` command is invoked as either one of :

- `groupget Options`
- `groupget GrID`

**Description :** `groupget` returns a linkage group as a list of markers from its group number (or so-called Group ID). The command `group` must have been called before hand to compute these groups.

**Arguments :**

- *Options*: `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *GrID*: the number of the group to return.

**Returns :** The contents of the linkage group as a list of markers.

**Example :**

```

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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...

```

```

CG> group 0.3 3

Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=30.00:

Group ID : Marker ID List ...
  1 : 52
  2 : 42 48 47 45 46 44 43
  3 : 41
  4 : 38
  5 : 37 39
  6 : 36 40
  7 : 35
  8 : 25
  9 : 22
 10 : 19 32 31 28 30 27 26 20 21
 11 : 13 14
 12 : 11 12
 13 : 10 15 16 18 17
 14 : 7
 15 : 6 51 8 53 50 9
 16 : 4 34 33 24 23 5
 17 : 3 29
 18 : 2 49
 19 : 1
19
CG> groupget 10
19 32 31 28 30 27 26 20 21
CG> mrkselset [groupget 10]

CG> sem

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
  1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

```

#### See also :

- `group` (2.3.18)

### 2.3.20 `groupmerge`

Sets the current marker selection list to the list of all the markers appearing in the groups indicated.

**Synopsis :** The CarthaGene `groupmerge` command is invoked as:

- `groupmerge GrID1 GrID2...`

**Description :** `groupmerge` sets the current list of selected markers to the union of all the markers that appear in the indicated linkage groups. The groups are indicated by their group number (so-called Group ID). The command `group` must have been called before hand to compute these groups. This command can be useful if you know that two different groups correspond to a single chromosome in practice.

**Arguments:**

- *GrID\**: the number of the groups to merge.

**Returns :** Nothing.

**Example :**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> group 0.5 3

Linkage Groups :
-----:
LOD threshold=3.00
Distance threshold=50.00:

Group ID : Marker ID List ...
  1 : 13 35 14
  2 : 10 18 17 16 15 11 12
  3 : 7
  4 : 6 53 52 8 51 50 9
  5 : 4 34 33 24 23 5 25
  6 : 3 32 29 31 30 28 27 26 20 19 21 22
  7 : 2 49 48 47 46 45 44 43 42 38 37 40 39 36 41
  8 : 1

8
CG> groupmerge 3 4 5

CG> mrkselget
7 6 53 52 8 51 50 9 4 34 33 24 23 5 25
```

**See also :**

- group (2.3.18)

**2.3.21 multigroup**

Merge large linkage groups found on several biological datasets given as arguments.

**Synopsis:** The multigroup command is invoked as either:

- multigroup *Options*
- multigroup *SizeThres ListOfDistThres ListOfLODThres ListOfDataFileName*

**Description:** Given a set of markers that are supposed to be on the same chromosome, the aim of the `multigroup` command is to detect erroneous markers that appear to be poorly linked to the rest of the markers in at least one dataset among several datasets. These erroneous markers can be removed from the current marker selection before computing the best map.

The `multigroup` command loads a set of biological dataset found in `ListOfDataFileName` parameter and returns a list of markers such that each marker belongs to a sufficiently large linkage group (of size greater than or equal to `SizeThres` parameter) in **EVERY** biological datasets. Linkage groups are computed by a 2-point analysis with `ListOfDistThres` and `ListOfLODThres` parameters which specify for each biological data set the distance (in Morgan or in Ray) and LOD thresholds, as used in the usual CarthaGene `group` command.

### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *SizeThres*: the minimum size for a linkage group to be kept in the final marker selection list.
- *ListOfDistThres*: an ordered list of maximum two-point distance (Haldane/Ray) corresponding to each dataset.
- *ListOfLODThres*: an ordered list of minimum two-point LOD corresponding to each dataset.
- *ListOfDataFileName*: an ordered list of biological datasets to be loaded.

**Returns:** a set of markers.

### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
# load two datasets and find markers which appear in linkage groups
```

```
# of size greater than 4 in the two datasets
```

```
CG> set mrkselection [multigroup 4 {0.5 0.5} {6 6} {Data/panelRH1.id Data/p...
```

```
Linkage Groups :
```

```
-----;
```

```
LOD threshold=6.00
```

```
Distance threshold=50.00:
```

```
Group ID : Marker ID List ...
```

```
1 : 151
```

```
2 : 125
```

```
3 : 93
```

```
4 : 15
```

```
5 : 4 36 60 73 79 104 118 123 138 150 161 160 159 158 157 156 155 1...
```

```
6 : 1 10 3 2
```

```
Linkage Groups :
```

```

-----:
LOD threshold=6.00
Distance threshold=50.00:

Group ID : Marker ID List ...
  1 : 151
  2 : 149
  3 : 123
  4 : 122 129 130 131 127 128 126 125 124 137 140 145 146 144 143 142...
  5 : 121
  6 : 119 120
  7 : 118
  8 : 116
  9 : 115 117
 10 : 110 114 113 112 111
 11 : 102
 12 : 93
 13 : 80 81 85 92 100 106 103 105 104 101 99 97 96 95 94 91 98 90 89 ...
 14 : 79
 15 : 74 78 77 76 75
 16 : 73
 17 : 59 63 69 72 71 68 67 66 65 64 62 61 60 70
 18 : 58
 19 : 46 55 57 56 54 53 52 51 50 49 48 47
 20 : 41 45 44 43 42
 21 : 40
 22 : 35 36 37 39 38
 23 : 30 31
 24 : 11 15 20 28 33 32 29 24 27 26 25 23 22 21 19 18 17 14 16 13 12 34
 25 : 10
 26 : 4 9 8 7 6 5
 27 : 1 3 2
122 129 130 131 127 128 126 124 137 140 145 146 144 143 142 141 139 138 136...
CG>

# merge the two panels
CG> dsmergor 1 2
{3 merged by order 161 273}
CG>

# set the current selection of markers
CG> mrkselset $mrkselection

CG>

# remove double markers
CG> mrkdouble

Possible double markers:

          4 = 5          [45.9]

CG> mrkmerges
Markers 4 and 5 merged in 4.

CG>

```

```
# find a good map
CG> lkhn 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
```

```
Map -1 : log10-likelihood = -2857.94
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : 105 98 87 89 90 97 99 101 100 104 103 108 114 111 112 113 110 109 10...
2 : 105 98 87 89 90 97 99 101 100 104 103 108 114 111 112 113 110 109 10...
```

```
CG> bestprintd
```

```
Map 0 : log10-likelihood = -2857.94, log-e-likelihood = -6580.66
```

```
-----:
```

```
Data Set Number 1 :
```

Pos	Id name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	105 105	35.5 cR	0.0 cR	29.9 %%	5.7
2	98 98	45.2 cR	35.5 cR	36.3 %%	4.8
3	87 87	18.2 cR	80.7 cR	16.6 %%	9.0
4	89 89	21.1 cR	98.8 cR	19.1 %%	9.6
5	90 90	60.7 cR	120.0 cR	45.5 %%	6.1
6	97 97	9.6 cR	180.7 cR	9.1 %%	17.4
7	99 99	3.2 cR	190.2 cR	3.1 %%	20.1
8	101 101	3.7 cR	193.4 cR	3.6 %%	18.9
9	100 100	20.1 cR	197.1 cR	18.2 %%	13.2
10	104 104	10.4 cR	217.2 cR	9.9 %%	14.0
11	103 103	18.0 cR	227.6 cR	16.5 %%	11.6
12	108 108	3.2 cR	245.7 cR	3.2 %%	19.5
13	114 114	3.2 cR	248.9 cR	3.2 %%	19.5
14	111 111	6.8 cR	252.1 cR	6.5 %%	15.8
15	112 112	10.4 cR	258.9 cR	9.9 %%	14.0
16	113 113	3.3 cR	269.3 cR	3.2 %%	19.1
17	110 110	0.0 cR	272.5 cR	0.0 %%	21.7
18	109 109	3.3 cR	272.6 cR	3.2 %%	19.1
19	107 107	7.9 cR	275.8 cR	7.6 %%	15.1
20	106 106	50.5 cR	283.8 cR	39.7 %%	5.3
21	77 77	46.9 cR	334.3 cR	37.4 %%	5.5
22	74 74	17.2 cR	381.2 cR	15.8 %%	13.9
23	75 75	0.0 cR	398.4 cR	0.0 %%	22.1
24	76 76	6.2 cR	398.4 cR	6.0 %%	18.5
25	78 78	39.1 cR	404.6 cR	32.4 %%	8.9
26	80 80	34.3 cR	443.7 cR	29.1 %%	7.7
27	81 81	14.4 cR	478.0 cR	13.4 %%	12.4
28	82 82	3.2 cR	492.4 cR	3.2 %%	19.6
29	83 83	30.2 cR	495.6 cR	26.1 %%	9.4
30	84 84	20.5 cR	525.8 cR	18.5 %%	10.9
31	85 85	17.8 cR	546.3 cR	16.3 %%	12.9
32	86 86	10.7 cR	564.1 cR	10.2 %%	17.3
33	88 88	6.1 cR	574.8 cR	5.9 %%	19.4
34	91 91	3.7 cR	580.9 cR	3.6 %%	19.8
35	92 92	16.9 cR	584.6 cR	15.5 %%	14.1
36	96 96	0.0 cR	601.5 cR	0.0 %%	19.0
37	95 95	28.5 cR	601.5 cR	24.8 %%	9.6
38	94 94	84.9 cR	630.0 cR	57.2 %%	1.3

39	44	44	35.2	cR	714.9	cR	29.7	%%	3.0
40	14	14	53.4	cR	750.1	cR	41.4	%%	2.9
41	35	35	15.4	cR	803.5	cR	14.3	%%	8.2
42	39	39	38.1	cR	818.9	cR	31.7	%%	5.4
43	38	38	8.0	cR	857.0	cR	7.7	%%	13.8
44	37	37	11.2	cR	865.0	cR	10.6	%%	12.8
45	36	36	67.8	cR	876.2	cR	49.2	%%	4.6
46	9	9	19.4	cR	944.0	cR	17.6	%%	14.9
47	8	8	0.0	cR	963.4	cR	0.0	%%	18.6
48	7	7	25.0	cR	963.4	cR	22.1	%%	12.1
49	6	6	20.8	cR	988.4	cR	18.8	%%	10.0
50	5	5	0.0	cR	1009.2	cR	0.0	%%	-----
50	4	4	20.3	cR	1009.2	cR	18.3	%%	12.3
51	11	11	41.7	cR	1029.5	cR	34.1	%%	6.7
52	12	12	15.8	cR	1071.2	cR	14.6	%%	10.6
53	13	13	11.1	cR	1087.0	cR	10.6	%%	12.8
54	17	17	3.6	cR	1098.2	cR	3.5	%%	15.9
55	16	16	0.0	cR	1101.7	cR	0.0	%%	19.3
56	18	18	3.6	cR	1101.7	cR	3.5	%%	15.9
57	19	19	7.2	cR	1105.3	cR	7.0	%%	14.6
58	21	21	8.9	cR	1112.5	cR	8.5	%%	14.6
59	20	20	12.0	cR	1121.4	cR	11.3	%%	12.4
60	24	24	14.2	cR	1133.4	cR	13.2	%%	10.7
61	27	27	9.7	cR	1147.6	cR	9.2	%%	12.4
62	23	23	9.6	cR	1157.3	cR	9.2	%%	13.2
63	22	22	15.4	cR	1166.9	cR	14.2	%%	12.0
64	26	26	7.4	cR	1182.3	cR	7.1	%%	14.7
65	25	25	24.8	cR	1189.7	cR	21.9	%%	9.1
66	28	28	7.5	cR	1214.4	cR	7.3	%%	14.4
67	29	29	0.0	cR	1222.0	cR	0.0	%%	17.0
68	32	32	3.6	cR	1222.0	cR	3.5	%%	16.7
69	33	33	3.6	cR	1225.6	cR	3.5	%%	16.7
70	34	34	47.8	cR	1229.1	cR	38.0	%%	5.0
71	57	57	9.7	cR	1276.9	cR	9.2	%%	10.6
72	56	56	49.3	cR	1286.6	cR	38.9	%%	6.0
73	60	60	13.6	cR	1335.9	cR	12.7	%%	12.0
74	64	64	33.2	cR	1349.5	cR	28.2	%%	6.6
75	67	67	39.7	cR	1382.7	cR	32.8	%%	6.3
76	68	68	3.6	cR	1422.4	cR	3.6	%%	19.9
77	70	70	16.7	cR	1426.1	cR	15.4	%%	15.5
78	72	72	6.6	cR	1442.8	cR	6.4	%%	15.4
79	71	71	11.0	cR	1449.4	cR	10.4	%%	14.2
80	69	69	23.6	cR	1460.3	cR	21.0	%%	11.5
81	66	66	11.9	cR	1484.0	cR	11.2	%%	13.1
82	65	65	21.4	cR	1495.9	cR	19.2	%%	10.5
83	63	63	20.4	cR	1517.2	cR	18.4	%%	12.1
84	62	62	6.0	cR	1537.6	cR	5.8	%%	19.4
85	61	61	26.7	cR	1543.6	cR	23.4	%%	11.7
86	59	59	6.5	cR	1570.3	cR	6.3	%%	17.5
87	52	52	3.2	cR	1576.8	cR	3.2	%%	19.6
88	55	55	10.2	cR	1580.0	cR	9.7	%%	15.3
89	49	49	14.3	cR	1590.2	cR	13.3	%%	13.3
90	51	51	0.0	cR	1604.5	cR	0.0	%%	18.2
91	54	54	6.7	cR	1604.5	cR	6.5	%%	17.1
92	53	53	0.0	cR	1611.2	cR	0.0	%%	21.0
93	48	48	0.0	cR	1611.2	cR	0.0	%%	21.7
94	50	50	0.0	cR	1611.2	cR	0.0	%%	21.7
95	47	47	8.7	cR	1611.2	cR	8.3	%%	15.7



96	46	46	23.4	cR	1619.9	cR	20.8	%%	12.0
97	41	41	26.9	cR	1643.3	cR	23.6	%%	10.1
98	42	42	7.0	cR	1670.2	cR	6.8	%%	15.9
99	43	43	3.4	cR	1677.2	cR	3.4	%%	17.9
100	45	45	164.1	cR	1680.6	cR	80.6	%%	0.5
101	136	136	19.2	cR	1844.7	cR	17.5	%%	7.3
102	131	131	22.4	cR	1863.9	cR	20.0	%%	8.2
103	133	133	78.1	cR	1886.2	cR	54.2	%%	3.6
104	147	147	28.8	cR	1964.3	cR	25.0	%%	10.1
105	152	152	13.1	cR	1993.1	cR	12.3	%%	15.0
106	150	150	27.2	cR	2006.2	cR	23.8	%%	12.3
107	157	157	11.6	cR	2033.4	cR	11.0	%%	17.6
108	156	156	26.3	cR	2045.0	cR	23.1	%%	11.6
109	154	154	9.9	cR	2071.3	cR	9.4	%%	15.7
110	159	159	14.3	cR	2081.2	cR	13.3	%%	16.9
111	161	161	0.0	cR	2095.5	cR	0.0	%%	26.5
112	160	160	11.2	cR	2095.5	cR	10.6	%%	18.4
113	158	158	8.4	cR	2106.7	cR	8.1	%%	19.1
114	155	155	11.2	cR	2115.1	cR	10.6	%%	18.4
115	153	153	5.7	cR	2126.3	cR	5.5	%%	20.6
116	148	148	5.8	cR	2132.0	cR	5.6	%%	19.7
117	146	146	17.9	cR	2137.8	cR	16.4	%%	15.2
118	143	143	8.7	cR	2155.7	cR	8.3	%%	19.2
119	145	145	3.4	cR	2164.4	cR	3.3	%%	20.7
120	144	144	50.1	cR	2167.7	cR	39.4	%%	7.4
121	138	138	19.3	cR	2217.8	cR	17.6	%%	12.9
122	141	141	8.8	cR	2237.1	cR	8.4	%%	16.9
123	142	142	10.0	cR	2245.9	cR	9.5	%%	13.9
124	139	139	10.0	cR	2255.9	cR	9.5	%%	13.9
125	140	140	3.2	cR	2265.9	cR	3.1	%%	20.1
126	132	132	3.2	cR	2269.0	cR	3.1	%%	20.1
127	137	137	0.0	cR	2272.2	cR	0.0	%%	22.7
128	135	135	10.0	cR	2272.2	cR	9.5	%%	16.4
129	134	134	39.5	cR	2282.2	cR	32.6	%%	6.6
130	129	129	18.6	cR	2321.7	cR	16.9	%%	8.9
131	128	128	22.5	cR	2340.2	cR	20.2	%%	7.3
132	130	130	46.4	cR	2362.8	cR	37.1	%%	4.5
133	127	127	18.8	cR	2409.2	cR	17.1	%%	8.9
134	126	126	25.7	cR	2427.9	cR	22.7	%%	9.6
135	124	124	22.3	cR	2453.7	cR	20.0	%%	11.5
136	122	122	-----						
			2475.9	cR					

136 markers, log10-likelihood = -904.61  
log-e-likelihood = -2082.94  
retention proba. = 0.20

Data Set Number 2 :

Pos	Id name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	105 105	67.4 cR	0.0 cR	49.0 %%	5.8
2	98 98	44.6 cR	67.4 cR	36.0 %%	7.9
3	87 87	30.0 cR	112.0 cR	25.9 %%	7.9
4	89 89	9.4 cR	142.0 cR	9.0 %%	12.7
5	90 90	43.7 cR	151.5 cR	35.4 %%	9.5

6	97	97	49.2	cR	195.1	cR	38.8	%%	10.9
7	99	99	17.3	cR	244.3	cR	15.9	%%	21.9
8	101	101	6.5	cR	261.6	cR	6.3	%%	29.6
9	100	100	15.6	cR	268.2	cR	14.5	%%	24.8
10	104	104	18.5	cR	283.8	cR	16.9	%%	22.6
11	103	103	72.0	cR	302.3	cR	51.3	%%	6.2
12	108	108	106.2	cR	374.2	cR	65.4	%%	3.5
13	114	114	32.4	cR	480.4	cR	27.7	%%	12.9
14	111	111	12.0	cR	512.8	cR	11.3	%%	21.8
15	112	112	0.0	cR	524.8	cR	0.0	%%	34.4
16	113	113	13.4	cR	524.8	cR	12.5	%%	25.1
17	110	110	61.7	cR	538.1	cR	46.0	%%	10.6
18	109	109	22.4	cR	599.8	cR	20.1	%%	22.1
19	107	107	23.6	cR	622.2	cR	21.0	%%	18.4
20	106	106	159.6	cR	645.8	cR	79.7	%%	1.6
21	77	77	16.4	cR	805.4	cR	15.1	%%	18.6
22	74	74	30.6	cR	821.8	cR	26.3	%%	12.6
23	75	75	18.4	cR	852.4	cR	16.8	%%	16.2
24	76	76	14.5	cR	870.8	cR	13.5	%%	19.5
25	78	78	89.6	cR	885.3	cR	59.2	%%	5.2
26	80	80	37.3	cR	974.9	cR	31.2	%%	11.7
27	81	81	19.7	cR	1012.2	cR	17.9	%%	16.9
28	82	82	19.6	cR	1032.0	cR	17.8	%%	19.2
29	83	83	34.4	cR	1051.6	cR	29.1	%%	14.5
30	84	84	26.6	cR	1085.9	cR	23.4	%%	18.3
31	85	85	24.1	cR	1112.5	cR	21.4	%%	19.1
32	86	86	9.9	cR	1136.7	cR	9.4	%%	23.8
33	88	88	33.9	cR	1146.6	cR	28.7	%%	12.9
34	91	91	7.1	cR	1180.4	cR	6.9	%%	25.5
35	92	92	14.6	cR	1187.6	cR	13.6	%%	22.4
36	96	96	25.6	cR	1202.2	cR	22.6	%%	17.8
37	95	95	7.1	cR	1227.8	cR	6.9	%%	26.4
38	94	94	156.6	cR	1234.9	cR	79.1	%%	0.7
39	44	44	507.3	cR	1391.6	cR	99.4	%%	-0.0
40	14	14	253.4	cR	1898.8	cR	92.1	%%	0.0
41	35	35	49.8	cR	2152.2	cR	39.2	%%	5.6
42	39	39	18.6	cR	2202.0	cR	17.0	%%	9.2
43	38	38	76.3	cR	2220.7	cR	53.4	%%	4.8
44	37	37	43.3	cR	2297.0	cR	35.1	%%	10.5
45	36	36	299.7	cR	2340.3	cR	95.0	%%	0.0
46	9	9	31.1	cR	2640.0	cR	26.7	%%	9.0
47	8	8	9.5	cR	2671.1	cR	9.1	%%	14.0
48	7	7	25.8	cR	2680.6	cR	22.7	%%	11.3
49	6	6	8.5	cR	2706.4	cR	8.1	%%	18.9
50	5	5	0.0	cR	2714.9	cR	0.0	%%	-----
50	4	4	85.6	cR	2714.9	cR	57.5	%%	2.7
51	11	11	11.9	cR	2800.5	cR	11.2	%%	16.1
52	12	12	12.4	cR	2812.4	cR	11.7	%%	17.0
53	13	13	29.9	cR	2824.8	cR	25.8	%%	12.4
54	17	17	12.2	cR	2854.7	cR	11.5	%%	20.5
55	16	16	8.7	cR	2866.9	cR	8.3	%%	23.3
56	18	18	16.2	cR	2875.6	cR	14.9	%%	18.7
57	19	19	10.5	cR	2891.8	cR	9.9	%%	21.4
58	21	21	5.0	cR	2902.3	cR	4.9	%%	25.3
59	20	20	41.1	cR	2907.3	cR	33.7	%%	8.5
60	24	24	16.2	cR	2948.3	cR	14.9	%%	12.4
61	27	27	12.2	cR	2964.5	cR	11.5	%%	15.1
62	23	23	0.0	cR	2976.7	cR	0.0	%%	22.3

63	22	22	9.9	cR	2976.7	cR	9.4	%%	18.1
64	26	26	4.6	cR	2986.6	cR	4.5	%%	20.4
65	25	25	14.0	cR	2991.2	cR	13.1	%%	17.9
66	28	28	42.4	cR	3005.2	cR	34.6	%%	7.6
67	29	29	18.7	cR	3047.6	cR	17.1	%%	11.3
68	32	32	34.4	cR	3066.4	cR	29.1	%%	9.8
69	33	33	14.8	cR	3100.8	cR	13.7	%%	17.0
70	34	34	113.5	cR	3115.6	cR	67.9	%%	3.5
71	57	57	2.4	cR	3229.1	cR	2.4	%%	30.6
72	56	56	65.6	cR	3231.5	cR	48.1	%%	9.1
73	60	60	28.1	cR	3297.1	cR	24.5	%%	14.0
74	64	64	35.3	cR	3325.2	cR	29.7	%%	10.1
75	67	67	14.0	cR	3360.5	cR	13.1	%%	17.9
76	68	68	38.7	cR	3374.5	cR	32.1	%%	7.6
77	70	70	49.2	cR	3413.2	cR	38.8	%%	5.4
78	72	72	42.3	cR	3462.4	cR	34.5	%%	10.3
79	71	71	9.7	cR	3504.7	cR	9.2	%%	24.5
80	69	69	30.9	cR	3514.4	cR	26.6	%%	16.4
81	66	66	17.1	cR	3545.3	cR	15.7	%%	21.5
82	65	65	17.8	cR	3562.4	cR	16.3	%%	20.1
83	63	63	14.3	cR	3580.2	cR	13.4	%%	23.2
84	62	62	2.3	cR	3594.5	cR	2.3	%%	31.4
85	61	61	39.6	cR	3596.8	cR	32.7	%%	15.1
86	59	59	140.3	cR	3636.5	cR	75.4	%%	1.5
87	52	52	69.3	cR	3776.7	cR	50.0	%%	6.2
88	55	55	34.1	cR	3846.1	cR	28.9	%%	16.7
89	49	49	14.4	cR	3880.1	cR	13.4	%%	22.8
90	51	51	20.8	cR	3894.5	cR	18.8	%%	18.5
91	54	54	13.2	cR	3915.4	cR	12.3	%%	19.5
92	53	53	19.4	cR	3928.5	cR	17.6	%%	15.3
93	48	48	12.0	cR	3947.9	cR	11.3	%%	20.5
94	50	50	8.7	cR	3959.9	cR	8.3	%%	22.4
95	47	47	12.6	cR	3968.6	cR	11.9	%%	21.1
96	46	46	60.1	cR	3981.2	cR	45.2	%%	7.5
97	41	41	5.6	cR	4041.3	cR	5.5	%%	21.0
98	42	42	2.7	cR	4046.9	cR	2.7	%%	23.3
99	43	43	5.6	cR	4049.7	cR	5.5	%%	21.0
100	45	45	96.4	cR	4055.3	cR	61.9	%%	2.5
101	136	136	87.7	cR	4151.7	cR	58.4	%%	3.4
102	131	131	14.3	cR	4239.4	cR	13.4	%%	16.9
103	133	133	189.4	cR	4253.7	cR	85.0	%%	0.6
104	147	147	139.3	cR	4443.1	cR	75.2	%%	1.9
105	152	152	29.2	cR	4582.4	cR	25.3	%%	17.5
106	150	150	33.5	cR	4611.6	cR	28.4	%%	17.4
107	157	157	25.0	cR	4645.0	cR	22.2	%%	19.5
108	156	156	23.0	cR	4670.1	cR	20.6	%%	20.4
109	154	154	32.3	cR	4693.1	cR	27.6	%%	17.6
110	159	159	23.8	cR	4725.4	cR	21.2	%%	22.5
111	161	161	23.8	cR	4749.2	cR	21.2	%%	22.5
112	160	160	14.8	cR	4773.0	cR	13.7	%%	25.1
113	158	158	12.3	cR	4787.8	cR	11.6	%%	26.1
114	155	155	17.3	cR	4800.1	cR	15.8	%%	25.1
115	153	153	46.0	cR	4817.3	cR	36.9	%%	12.9
116	148	148	31.8	cR	4863.3	cR	27.3	%%	17.4
117	146	146	45.0	cR	4895.2	cR	36.2	%%	15.1
118	143	143	25.5	cR	4940.2	cR	22.5	%%	22.1
119	145	145	7.0	cR	4965.7	cR	6.7	%%	30.8
120	144	144	63.7	cR	4972.7	cR	47.1	%%	9.6

121	138	138	20.8	cR	5036.4	cR	18.8	%%	15.3
122	141	141	39.2	cR	5057.2	cR	32.5	%%	10.4
123	142	142	19.2	cR	5096.5	cR	17.5	%%	20.0
124	139	139	4.6	cR	5115.7	cR	4.5	%%	29.8
125	140	140	19.8	cR	5120.3	cR	17.9	%%	23.6
126	132	132	22.0	cR	5140.1	cR	19.7	%%	22.7
127	137	137	17.2	cR	5162.0	cR	15.8	%%	22.8
128	135	135	20.0	cR	5179.2	cR	18.1	%%	18.5
129	134	134	69.8	cR	5199.2	cR	50.2	%%	6.0
130	129	129	10.5	cR	5269.0	cR	10.0	%%	21.8
131	128	128	8.6	cR	5279.5	cR	8.3	%%	23.8
132	130	130	17.2	cR	5288.2	cR	15.8	%%	20.7
133	127	127	2.6	cR	5305.3	cR	2.6	%%	33.4
134	126	126	7.9	cR	5307.9	cR	7.6	%%	31.1
135	124	124	50.5	cR	5315.8	cR	39.6	%%	10.4
136	122	122	-----						
			5366.3	cR					

```

136 markers, log10-likelihood = -1953.33
log-e-likelihood = -4497.72
retention proba. = 0.14
0
CG>

```

**See also:**

- group (2.3.18)

## 2.4 Maps and the Heap

A map in `CARHAGENE` defines the parameters of a probabilistic model of the genetic/RH data available on the currently active set of markers. In the simplest cases (eg. one genetic population), a map is completely defined by two components: an order of the markers and the recombination probabilities between adjacent markers. As in most existing mapping software (eg. MapMaker), all the probabilistic models used in `CARHAGENE` assume a complete absence of interference on genetic data. In the case of RH data, recombination probabilities are replaced by breakage probabilities along with a retention probability parameter. The probabilistic model used is the so-called “equal retention model” [LBLC95] which seems to be an ideal compromise between simplicity, efficiency and realism. Given a map, since all the parameters of the probabilistic model are fixed by the map, it is possible to compute the probability of the data given the model often coined as the likelihood of the data. Note that the continuous part of the probabilistic model (probabilities) are always estimated using a maximum-likelihood criterion in `CARHAGENE`. This criterion is a rigorous criterion which has several attractive theoretical properties. It is optimised in `CARHAGENE` using variants of the EM algorithm [DLR77].

The probabilistic parameters used in the model can be converted to so-called distances using traditional mapping functions: Haldane and Kosambi that convert recombination probabilities to Morgans for genetic data and the usual  $-\log(1.0 - \theta)$  for mapping breakage probabilities to Rays. Note that the probabilistic model used is consistent with Haldane mapping function. The Kosambi mapping function, which is usually the favorite one, has theoretical weaknesses and we advise not to use it.

When several datasets are merged using the `dsmergen` command, since the underlying assumption is that all datasets share the same parameters, a single “consensus” map suffices to define a probabilistic model for

all the data. But such maps do not suffice for more complex models, eg. when several datasets are merged using the `dsmergor` command. In this case, the assumption is that all dataset merged using `dsmergor` share a consistent order but each with different specific distances (i.e., probabilities).

In this case, a map is defined by a collection of simple maps (as above) that share a consistent order.

### 2.4.1 The heap

As long as the set of selected markers is unchanged, all the maps produced and examined by `CARTHAGENE` in all the mapping process are tentatively stored in a central map storage called “the heap”<sup>1</sup>. The heap remembers all the  $k$  best (w.r.t. the loglikelihood) maps found since the last time the marker selection was changed. The parameter  $k$  is user configurable using the `heapsize` command.

To actually visualize the maps stored in the heap, you can use either a standard or detailed impression of the contents of the heap. This is done using respectively the `heaprint` and `heaprintd` commands. The whole content of the heap can be fetch and stored in a list (for further analysis using the scripting language Tcl) with the `heapget` command.

Actually, each map stored in the heap has a numerical Id and this numerical id can be used to print/fetch the maps stored in the heap. This is done using respectively the `maprint` and `maprintd` commands or the `mapget` command. Because the maps are always stored in the heap in a “standardized” order, a `maprintdr` function is also available to print a map using a reverse marker order. It is also possible to compute the number of obligate chromosome breaks of a map using the `mapocb` command. Finally, if you only want to access the order of the markers used in a map, the command `mapordget` will returns the marker ordering of the map indicated in a list.

The heap main use is to provide an approximation of all the markers ordering around the optimal markers ordering. The heap can be directly examined using the previous `heaprint` commands but a specific command is available to perform the analysis of alternative maps in the heap. The `heaprinto` command dumps all orders in the heap, one by line, from the best to the worst. For each such order, the way the order differs from the order of the original map is made explicit and the difference of loglikelihood with the best map is reported.

A graphical representation of maps and the heap is given by `maprintg`, `maprintv` (only on Linux computers) and `heaprintg` commands.

### 2.4.2 heapsize

Resize the Heap.

**Synopsis :** The CarthaGene `heapsize` command is invoked as either one of :

- `heapsize Options`
- `heapsize NbMap`

**Description :** `heapsize` enables to resize the heap. Even if the heap already contains maps, the  $k$  best maps are kept where  $k$  is the new size. If the size of a full heap is decreased, the worst maps are lost. The size of the heap as a limited impact on CarthaGène efficiency and sizes up to 1023 should be fine.

---

<sup>1</sup>This is the usual name for the data structure [CLR90] used in `CARTHAGENE` to actually store the map. In practice, a hash map is also used to check if a map already appears in the heap.

## Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *NbMap* : The number of maps the heap must contain. The *NbMap* argument must be a positive non null integer.

## Example :

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.

Type 'help' for help.

# starting with a heap of size 7
CG> heapsize 7

# filling it
CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -479.22
-----:
Set : Marker List ...
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 MS1\
9 MS1

CG> flips 3 3.0 1
...
CG> heapprint

Map 0 : log10-likelihood = -448.72
-----:
Set : Marker List ...
1 : MS6 MS5 MS4 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 MS2\
0 MS1

Map 2 : log10-likelihood = -448.56
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS17 MS16 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 MS2\
0 MS1

Map 6 : log10-likelihood = -448.07
-----:
Set : Marker List ...
1 : MS6 MS5 MS4 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 MS2\
0 MS1

Map 1 : log10-likelihood = -446.75
-----:
Set : Marker List ...
```

```

    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS20 MS1\
9 MS1

Map  4 : log10-likelihood =  -446.09
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS20 MS1\
9 MS1

Map  5 : log10-likelihood =  -445.95
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 MS2\
0 MS1

Map  3 : log10-likelihood =  -445.30
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 MS2\
0 MS1

# keeping the 3 best one.
CG> heapsize 3

CG> heapprint

Map  0 : log10-likelihood =  -446.09
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS20 MS1\
9 MS1

Map  1 : log10-likelihood =  -445.95
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 MS2\
0 MS1

Map  2 : log10-likelihood =  -445.30
-----:
Set  : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 MS2\
0 MS1

CG>

```

**See also :**

- `heapprint` (2.4.4)
- `heapprintd` (2.4.5)

### 2.4.3 `heapsizeget`

Get the size of the Heap.

**Synopsis :** The CarthaGene `heapsizeget` command is invoked as either one of :

- `heapsizeget Options`

**Description :** `heapsizeget` enables to get the size of the heap.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** a integer.

**Example :**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> heapsizeget
```

```
15
```

```
# incresing of 5 the size oh the heap
```

```
CG> heapsize [expr [heapsizeget] + 5]
```

```
CG> heapsizeget
```

```
20
```

```
CG>
```

**See also :**

- `heapsize (2.4.2)`

## 2.4.4 heaprint

Display the Heap of maps.

**Synopsis :** The CarthaGene `heaprint` command is invoked as either one of :

- `heaprint Options`
- `heaprint`

**Description :** `heaprint` provide a output of the heap of maps. The maps are ordered by loglikelihood. The best map is always the last printed. The informations available are the id of a map, the score, and the ordered list of the markers printed by names. If the data set the maps are computed on, is merged by order, relatives orders for each merged data sets are printed for each maps.



## Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.

## Example :

```
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Type 'help' for help.

# small heap for the example
CG> heapsize 3

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -479.22
-----:
Set : Marker List ...
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...

CG> flips 3 3.0 1
...
CG> heapprint

Map 0 : log10-likelihood = -446.09
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS20 M...

Map 1 : log10-likelihood = -445.95
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 M...

Map 2 : log10-likelihood = -445.30
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 M...

CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 21 326}
CG> sem

Map -1 : log10-likelihood = -795.54
-----:
Set : Marker List ...
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...
2 : MS4 MS5 MS6 MS8 MS7 MS3 MS9 MS15 ...
```

```

CG> flips 3 3.0 1
...
CG> heaprint

Map 0 : log10-likelihood = -722.37
-----:
Set : Marker List ...
  1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS7 MS8 MS9 MS3 MS2 MS12 MS15 MS19 M...
  2 : MS4 MS5 MS6                               MS7 MS8 MS9 MS3           MS15      ...

Map 2 : log10-likelihood = -722.17
-----:
Set : Marker List ...
  1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS9 MS8 MS7 MS3 MS2 MS12 MS15 MS19 M...
  2 : MS4 MS5 MS6                               MS9 MS8 MS7 MS3           MS15      ...

Map 1 : log10-likelihood = -721.93
-----:
Set : Marker List ...
  1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS7 MS9 MS8 MS3 MS2 MS12 MS15 MS19 M...
  2 : MS4 MS5 MS6                               MS7 MS9 MS8 MS3           MS15      ...

```

#### See also :

- `heapsize` (2.4.2)
- `heaprintd` (2.4.5)
- `heaprinto` (2.4.16)
- `maprint` (2.4.8)

### 2.4.5 `heaprintd`

Display the Heap of maps in details.

**Synopsis :** The CarthaGene `heaprintd` command is invoked as either one of :

- `heaprintd Options`
- `heaprintd`

**Description :** `heaprintd` provide a output of the heap of maps. The maps are ordered by loglikelihood. The best map is always the last printed. The informations available are the id of a map, the score, and the ordered list of the markers printed by names, ids and positions on the map. This last information is usefull for "merged by order" data sets. Distances and two points informations for consecutives markers are also available. At the end, some statistics are delivered to give the computational cost of the result.

If the data set the maps are computed on, is merged by order, relatives orders for each merged data sets are printed for each maps.

## Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.

## Example :

```
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under certain conditions. See the License file for information.

Type 'help' for help.

# a very small heap for the example
CG> heapsize 1

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -479.22
-----;
Set : Marker List ...
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...

# we fill the heap with the best map
CG> flips 3 0 0
...
# and look at it
CG> heaprintd

Map 0 : log10-likelihood = -454.55, log-e-likelihood = -1046.63
-----;

Data Set Number 1 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	1	MS4	3.1 cM	0.0 cM	3.0 cM	3.0 %%	21.1
2	2	MS5	4.0 cM	3.1 cM	3.9 cM	3.9 %%	15.4
3	4	MS6	28.2 cM	7.1 cM	23.0 cM	21.5 %%	5.1
4	5	MS11	8.0 cM	35.3 cM	7.4 cM	7.4 %%	11.9
5	3	MS13	39.8 cM	43.3 cM	30.9 cM	27.5 %%	0.9
6	6	MS17	22.1 cM	83.1 cM	18.7 cM	17.9 %%	6.3
7	7	MS16	33.5 cM	105.2 cM	26.7 cM	24.4 %%	10.3
8	8	MS8	6.3 cM	138.7 cM	5.9 cM	5.9 %%	35.1
9	9	MS7	17.2 cM	145.0 cM	15.0 cM	14.5 %%	21.1
10	10	MS2	0.6 cM	162.2 cM	0.6 cM	0.6 %%	47.6
11	11	MS3	28.9 cM	162.8 cM	23.6 cM	22.0 %%	12.8
12	12	MS9	20.8 cM	191.7 cM	17.7 cM	17.0 %%	13.6
13	13	MS15	3.6 cM	212.5 cM	3.5 cM	3.5 %%	26.5
14	14	MS12	51.8 cM	216.1 cM	38.3 cM	32.2 %%	4.3
15	15	MS20	2.9 cM	267.9 cM	2.8 cM	2.8 %%	34.8
16	16	MS19	345.4 cM	270.7 cM	190.0 cM	50.0 %%	-0.0

```

17 17 MS1          -----
                        616.1 cM
                        411.0 cM

17 markers, log10-likelihood = -454.55
log-e-likelihood = -1046.63

EM calls:
Set 1 : 67 (60,0)
CPU Time (secs): 0.00
Maps within -3.0: 1

# same thing with maps merged by order
CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/cartagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 21 326}
CG> sem

Map -1 : log10-likelihood = -795.54
-----:
Set : Marker List ...
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...
2 : MS4 MS5 MS6 MS8 MS7 MS3 MS9 MS15 ...

CG> flips 3 3.0 1
...
# each map is a pair of map
CG> heaprintd

Map 0 : log10-likelihood = -721.93, log-e-likelihood = -1662.30
-----:

Data Set Number 1 :

Pos  Id name      Markers Distance      Cumulative Distance  Theta  2pt
      Id name      Markers Haldane      Haldane      Kosambi  (%%age)  LOD
-----
1  1  MS4          3.1 cM      0.0 cM      3.0 cM      3.0 %%    21.1
2  2  MS5          3.8 cM      3.1 cM      3.7 cM      3.7 %%    15.4
3  4  MS6         26.1 cM      6.9 cM     21.6 cM     20.3 %%     5.1
4  5  MS11         8.6 cM     33.0 cM      8.0 cM      7.9 %%    11.9
5  3  MS13        14.3 cM     41.6 cM     12.7 cM     12.5 %%     9.7
6  7  MS16        19.6 cM     56.0 cM     16.8 cM     16.2 %%     6.3
7  6  MS17        60.6 cM     75.6 cM     43.6 cM     35.1 %%     0.0
8  9  MS7          5.7 cM    136.2 cM      5.4 cM      5.4 %%    29.4
9 12  MS9          1.9 cM    141.9 cM      1.8 cM      1.8 %%    40.8
10 8  MS8         25.8 cM    143.8 cM     21.4 cM     20.1 %%    15.1
11 11 MS3          0.6 cM    169.6 cM      0.6 cM      0.6 %%    47.6
12 10 MS2         62.0 cM    170.2 cM     44.4 cM     35.5 %%     4.3
13 14 MS12         4.3 cM    232.2 cM      4.1 cM      4.1 %%    26.5
14 13 MS15        41.3 cM    236.5 cM     31.8 cM     28.1 %%     6.9
15 16 MS19         2.9 cM    277.8 cM      2.9 cM      2.9 %%    34.8
16 15 MS20        345.4 cM    280.7 cM     190.0 cM     50.0 %%    -0.0
17 17 MS1          -----
                        626.1 cM
                        411.8 cM

```

```

17 markers, log10-likelihood = -441.26
log-e-likelihood = -1016.04

```

Data Set Number 2 :

Pos	Id name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	1 MS4	85.0 cR	0.0 cR	57.3 %%	3.6
2	2 MS5	57.9 cR	85.0 cR	44.0 %%	7.4
3	4 MS6	33.2 cR	143.0 cR	28.2 %%	12.8
8	9 MS7	77.0 cR	176.2 cR	53.7 %%	5.4
9	12 MS9	17.0 cR	253.2 cR	15.6 %%	18.5
10	8 MS8	233.1 cR	270.1 cR	90.3 %%	0.2
11	11 MS3	760.1 cR	503.3 cR	100.0 %%	-0.0
14	13 MS15	760.1 cR	1263.4 cR	100.0 %%	-0.0
17	17 MS1	95.5 cR	2023.4 cR	61.5 %%	2.7
18	20 G37	25.3 cR	2118.9 cR	22.4 %%	15.0
19	21 G40	21.5 cR	2144.2 cR	19.3 %%	17.2
20	18 G36	59.8 cR	2165.7 cR	45.0 %%	7.7
21	19 G39	----- 2225.5 cR			

```

13 markers, log10-likelihood = -280.67
log-e-likelihood = -646.26
retention proba. = 0.24

```

```

EM calls:
Set 3 : 876 (0,0)
Set 1 : 877 (855,0)
Set 2 : 877 (858,0)
CPU Time (secs): 0.06
Maps within -3.0: 1

```

#### See also :

- [heapsize \(2.4.2\)](#)
- [heaprint \(2.4.4\)](#)
- [heaprinto \(2.4.16\)](#)
- [maprintd \(2.4.9\)](#)

### 2.4.6 heapget

Return a list of maps of the heap.

**Synopsis :** The CarthaGene `heapget` command is invoked as either one of :

- `heapget Options`
- `heapget UnitFlag NbMap`

**Description :** heapget to dump maps from the heap to a list. This command is available for programming...

### Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *UnitFlag* : 'k' for Kosambi, 'h' for Haldane. This field is mandatory, but not used for RH data sets.
- *NbMap* : The number of best map to get. If set to 0, all the map of the heap are returned. A positive integer is expected.

**Returns :** A list of lists is returned :

```
{
  {MapId_0 MapScore_0 {DataSetId_0 OrderScore_0_0 MrkName_0_0_0 CumulDist_0_0_0 MrkName_0_0_1 CumulDist_0_0_1 ... MrkName_0_0_n CumulDist_0_0_n}
                     {DataSetId_1 OrderScore_0_1 MrkName_0_1_0 CumulDist_0_1_0 MrkName_0_1_1 CumulDist_0_1_1 ... MrkName_0_1_n CumulDist_0_1_n'}
                     ...
                     {DataSetId_m OrderScore_0_m MrkName_0_m_0 CumulDist_0_m_0 MrkName_0_m_1 CumulDist_0_m_1 ... MrkName_0_m_n CumulDist_0_m_n'}}
  }
  {MapId_1 MapScore_1 {DataSetId_0 OrderScore_1_0 MrkName_1_0_0 CumulDist_1_0_0 MrkName_1_0_1 CumulDist_1_0_1 ... MrkName_1_0_n CumulDist_1_0_n}
                     {DataSetId_1 OrderScore_1_1 MrkName_1_1_0 CumulDist_1_1_0 MrkName_1_1_1 CumulDist_1_1_1 ... MrkName_1_1_n CumulDist_1_1_n'}
                     ...
                     {DataSetId_m OrderScore_1_m MrkName_1_m_0 CumulDist_1_m_0 MrkName_1_m_1 CumulDist_1_m_1 ... MrkName_1_m_n CumulDist_1_m_n'}}
  }
  ...
  {MapId_l MapScore_l {DataSetId_0 OrderScore_l_0 MrkName_l_0_0 CumulDist_l_0_0 MrkName_l_0_1 CumulDist_l_0_1 ... MrkName_l_0_n CumulDist_l_0_n}
                     {DataSetId_1 OrderScore_l_1 MrkName_l_1_0 CumulDist_l_1_0 MrkName_l_1_1 CumulDist_l_1_1 ... MrkName_l_1_n CumulDist_l_1_n'}
                     ...
                     {DataSetId_m OrderScore_l_m MrkName_l_m_0 CumulDist_l_m_0 MrkName_l_m_1 CumulDist_l_m_1 ... MrkName_l_m_n CumulDist_l_m_n'}}
  }
}
```

Where l is NbMap, the number of map you get. Where m is the number of "merged by order" data sets. Where n is the number or markers of the map known by the data set.

### Example :

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Type 'help' for help.

# starting with a heap of size 7

CG> heapsize 7

# filling it

CG> dsload Data/bc1.cg

{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...

CG> sem

Map -1 : log10-likelihood = -479.22

-----:

Set : Marker List ...

1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...

CG> flips 3 3.0 1

...

CG> heaprint

```

Map 0 : log10-likelihood = -448.72
-----:
Set : Marker List ...
1 : MS6 MS5 MS4 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 M...

Map 2 : log10-likelihood = -448.56
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS17 MS16 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 M...

Map 6 : log10-likelihood = -448.07
-----:
Set : Marker List ...
1 : MS6 MS5 MS4 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 M...

Map 1 : log10-likelihood = -446.75
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS20 M...

Map 4 : log10-likelihood = -446.09
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS20 M...

Map 5 : log10-likelihood = -445.95
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 M...

Map 3 : log10-likelihood = -445.30
-----:
Set : Marker List ...
1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 M...

# getting the 3 best one.
CG> heapget k 3
{3 -445.30 {1 -445.30 MS4 0.0 MS5 3.0 MS6 6.7 MS11 28.2 MS13 36.2 MS16 48.9 M\
S17 64.7 MS8 105.1 MS7 111.0 MS3 125.2 MS2 125.8 MS9 149.4 MS12 164.7 MS15 16\
8.9 MS19 200.8 MS20 203.6 MS1 393.6}} {5 -445.95 {1 -445.95 MS4 0.0 MS5 3.0 M\
S6 6.7 MS11 28.2 MS13 36.2 MS16 48.9 MS17 64.7 MS8 105.1 MS7 111.0 MS2 125.7 \
MS3 126.3 MS9 149.8 MS12 165.1 MS15 169.2 MS19 200.9 MS20 203.7 MS1 393.8}} {\
4 -446.09 {1 -446.09 MS4 0.0 MS5 3.0 MS6 6.7 MS11 28.2 MS13 36.2 MS16 48.9 MS\
17 64.7 MS8 105.1 MS7 111.0 MS3 125.2 MS2 125.8 MS9 149.4 MS12 164.7 MS15 168\
.9 MS20 202.8 MS19 205.6 MS1 395.6}}
CG>

```

#### See also :

- [heaprint \(2.4.4\)](#)
- [heaprintd \(2.4.5\)](#)
- [mapget \(2.4.13\)](#)

## 2.4.7 heapordget

Return a list of all the marker orders appearing in the heap.

**Synopsis:** The CarthaGene `heapordget` command is invoked as:

- `heapordget`

**Description:** `heapordget` returns the list of all the markers orders used in all the maps appearing in the heap. Markers are denoted by their numerical Id and the set of orders returned as a list of lists of numerical Ids.

**Arguments:** None.

**Returns:** A list of lists of numerical Ids of markers is returned. Each elementary list in the global list corresponds to the order of the markers used in a map in the heap.

**Example :**

```
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Type 'help' for help.

# starting with a heap of size 3
CG> heapsize 3

# filling it
CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -479.22
-----:
Set : Marker List ...
    1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...

CG> flips 3 3.0 1
...
CG> heaprint

Map 0 : log10-likelihood = -446.09
-----:
Set : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS20 M...

Map 1 : log10-likelihood = -445.95
-----:
Set : Marker List ...
    1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS2 MS3 MS9 MS12 MS15 MS19 M...
```



```

Map 2 : log10-likelihood = -445.30
-----:
Set : Marker List ...
      1 : MS4 MS5 MS6 MS11 MS13 MS16 MS17 MS8 MS7 MS3 MS2 MS9 MS12 MS15 MS19 M...

# getting the corresponding orders
CG> heapordget
{1 2 4 5 3 7 6 8 9 11 10 12 14 13 16 15 17} {1 2 4 5 3 7 6 8 9 10 11 12 14 13\
16 15 17} {1 2 4 5 3 7 6 8 9 11 10 12 14 13 15 16 17}
CG>

```

#### See also :

- heaprint (2.4.4)
- heaprintd (2.4.5)
- mapget (2.4.6)

## 2.4.8 maprint

Concise describes the map whose numerical Id in the heap is given.

**Synopsis:** The `maprint` command is invoked either:

- `maprint Options`
- `maprint MapId`

**Description:** The `maprint` command prints a concise description of the map whose numerical id has been given as argument. The  $\log_{10}$ -likelihood of the map is printed followed by the order of all the markers (by name), and for each data-set.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *MapId*: the numerical id of the map in the heap.

**Returns:** nothing.

#### Example:

```
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```

```

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```

Type 'help' for help.

```
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> buildfw 3 3 {} 0
...
CG> maprint 0

Map 0 : log10-likelihood = -14.70
-----:
Set : Marker List ...
1 : MS8 MS10 MS14
```

**See also:**

- `maprintd` (2.4.9)
- `heaprint` (2.4.4)

## 2.4.9 `maprintd`

Precisely describes the map whose numerical Id in the heap is given.

**Synopsis:** The `maprintd` command is invoked either:

- `maprintd Options`
- `maprintd MapId`

**Description:** The `maprintd` command prints an extensive description of the map whose numerical id has been given as argument. For each data-set for which parameters have been estimated (merged using `mergor`), the map is described by successively giving, line per line:

1. the position of the marker in the overall map for this data set
2. the numerical Id of the marker
3. the name of the marker (truncated to a maximum number of characters)
4. the Haldane distance to the next marker (if any). Rays are used for RH data.
5. The cumulative distance of the marker from the beginning of the map (Haldane/Ray).
6. For genetic data, the Kosambi distance from the next marker (if any)
7. the estimated recombination ratio/breakage with the next marker
8. the two-points LOD with the next marker

Then the length of the map, the number of markers and the  $\log_{10}$  and natural logarithm of the likelihood of the map are displayed.

**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *MapId*: the numerical id of the map in the heap.

**Returns:** nothing.

**Example:**

```
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Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> buildfw 3 3 {} 0
...
CG> maprintd 0

Map 0 : log10-likelihood = -14.70, log-e-likelihood = -33.86
-----:

Data Set Number 1 :

Pos  Id name      Markers Distance      Cumulative Distance  Theta      2pt
      Id name      Markers Haldane      Haldane      Kosambi  (%%age)      LOD
-----
1   8  MS8          3.3 cM      0.0 cM      3.2 cM      3.2 %%      7.4
2  10 MS10         12.2 cM     3.3 cM     11.0 cM     10.8 %%      2.7
3  14 MS14         -----
                   15.5 cM                      14.2 cM

      3 markers, log10-likelihood = -14.70
                   log-e-likelihood = -33.86

CG>
```

**See also:**

- maprint (2.4.8)
- heaprintd (2.4.5)

**2.4.10 maprintdr**

Precisely describes the map whose numerical Id in the heap is given using a reverse order.

**Synopsis:** The `maprintdr` command is invoked either:

- `maprintdr Options`
- `maprintdr MapId`

**Description:** The `maprintdr` command prints an extensive description of the map whose numerical id has been given as argument using a reverse marker ordering. The purpose of using a reverse marker ordering is to perform an easier map comparison when two maps in the heap have order which are similar up to a map reversal. Otherwise, the commands performs as `maprintd`.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *MapId*: the numerical id of the map in the heap.

**Returns:** nothing.

**Example:**

```
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Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> buildfw 3 3 {} 0
...
CG> maprintd 0

Map 0 : log10-likelihood = -14.70, log-e-likelihood = -33.86
-----:

Data Set Number 1 :

Pos  Id name      Markers Distance      Cumulative Distance  Theta      2pt
      Id name      Haldane      Haldane      Kosambi      (%%age)      LOD
-----
1   8  MS8          3.3 cM        0.0 cM        3.2 cM        3.2 %%        7.4
2  10 MS10         12.2 cM       3.3 cM       11.0 cM       10.8 %%        2.7
3  14 MS14         -----
                        15.5 cM                        14.2 cM

      3 markers, log10-likelihood = -14.70
                        log-e-likelihood = -33.86

CG> maprintdr 0
```

```
Map 0 : log10-likelihood = -14.70, log-e-likelihood = -33.86
-----:
```

```
Data Set Number 1 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	14	MS14	12.2 cM	0.0 cM	11.0 cM	10.8 %%	2.7
2	10	MS10	3.3 cM	12.2 cM	3.2 cM	3.2 %%	7.4
3	8	MS8	-----		-----		
			15.5 cM		14.2 cM		

```
3 markers, log10-likelihood = -14.70
log-e-likelihood = -33.86
```

```
CG>
```

#### See also:

- maprint (2.4.8)
- heaprintd (2.4.5)

### 2.4.11 bestprint

Concisely describes the best map in the heap.

**Synopsis:** The `bestprint` command is invoked as:

- `bestprint`

**Description:** The `bestprint` command prints a concise description of the best map in the heap. The  $\log_{10}$ -likelihood of the map is printed followed by the order of all the markers (by name), and for each data-set.

**Arguments:** None.

**Returns:** nothing.

#### Example:

```
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```

```
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```

Type 'help' for help.

```
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem
```

```
Map -1 : log10-likelihood = -291.76
-----:
Set : Marker List ...
1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS...
```

```
CG> flips 6 0 1
...
CG> bestprint
```

```
Map 9 : log10-likelihood = -291.76
-----:
Set : Marker List ...
1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS13 MS12 MS14 MS15 MS...
9
```

#### See also:

- `bestprintd` (2.4.12)
- `heaprint` (2.4.4)

## 2.4.12 `bestprintd`

Precisely describes the best map in the heap.

**Synopsis:** The `bestprintd` command is invoked as:

- `bestprintd`

**Description:** The `bestprintd` command prints an extensive description of the best map in the heap. For each data-set for which parameters have been estimated (merged using `mergor`), the map is described by successively giving, line per line:

1. the position of the marker in the overall map for this data set
2. the numerical Id of the marker
3. the name of the marker (truncated to a maximum number of characters)
4. the Haldane distance to the next marker (if any). Rays are used for RH data.
5. The cumulative distance of the marker from the beginning of the map (Haldane/Ray).
6. For genetic data, the Kosambi distance from the next marker (if any)
7. the estimated recombination ratio/breakage with the next marker
8. the two-points LOD with the next marker

Then the length of the map, the number of markers and the  $\log_{10}$  and natural logarithm of the likelihood of the map are displayed.

**Arguments:** none.

**Returns:** nothing.

**Example:**

```
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Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -291.76
-----:
Set : Marker List ...
1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS...

CG> flips 6 0 1
...
CG> bestprintd

Map 9 : log10-likelihood = -291.76, log-e-likelihood = -671.79
-----:

Data Set Number 1 :
```

Pos	Id	name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%age)	2pt LOD
1	1	MS1		19.5 cM	0.0 cM	16.8 cM	16.2 %%	15.7
2	2	MS2		0.6 cM	19.5 cM	0.6 cM	0.6 %%	47.6
3	3	MS3		5.8 cM	20.1 cM	5.5 cM	5.5 %%	35.1
4	4	MS4		3.7 cM	25.9 cM	3.6 cM	3.5 %%	21.1
5	5	MS5		3.7 cM	29.6 cM	3.6 cM	3.6 %%	15.4
6	6	MS6		1.6 cM	33.3 cM	1.6 cM	1.6 %%	17.3
7	7	MS7		6.7 cM	34.9 cM	6.3 cM	6.3 %%	35.1
8	8	MS8		2.2 cM	41.6 cM	2.2 cM	2.2 %%	40.8
9	9	MS9		3.0 cM	43.8 cM	2.9 cM	2.9 %%	7.2
10	10	MS10		5.4 cM	46.8 cM	5.1 cM	5.1 %%	3.6
11	11	MS11		8.6 cM	52.2 cM	7.9 cM	7.9 %%	11.9
12	13	MS13		0.0 cM	60.7 cM	0.0 cM	0.0 %%	18.7
13	12	MS12		0.0 cM	60.7 cM	0.0 cM	0.0 %%	3.6
14	14	MS14		5.8 cM	60.7 cM	5.5 cM	5.5 %%	0.0
15	15	MS15		4.6 cM	66.6 cM	4.4 cM	4.4 %%	26.6
16	16	MS16		26.1 cM	71.1 cM	21.6 cM	20.3 %%	6.3
17	17	MS17		0.0 cM	97.2 cM	0.0 cM	0.0 %%	16.0
18	18	MS18		4.9 cM	97.2 cM	4.7 cM	4.6 %%	27.1
19	19	MS19		3.0 cM	102.1 cM	2.9 cM	2.9 %%	34.8
20	20	MS20		-----	-----	-----	-----	-----
				105.1 cM		95.0 cM		

```

20 markers, log10-likelihood = -291.76
              log-e-likelihood = -671.79

```

9

**See also:**

- `bestprint` (2.4.11)
- `maprint` (2.4.8)
- `maprint` (2.4.9)
- `maprint` (2.4.10)
- `heaprint` (2.4.4)

### 2.4.13 `mapget`

Returns a list describing the map with a given numerical Id in the heap.

**Synopsis:** The `mapget` command is invoked either as:

- `mapget Options`
- `mapget Unit MapId`

**Description:** The `mapget` command returns a list that describes the map whose numerical id in the heap is *MapId*. The list contains successively:

- the numerical Id of the map in the heap (*MapId*)
- the map's overall maximum loglikelihood (in  $\log_{10}$  units)
- a sequence of sublist, one for each current data-set for which parameters are estimated (merged by `mergor`). These sublists contain successively:
  - the data set numerical Id,
  - the map loglikelihood in this data-set (in  $\log_{10}$  units)
  - the name of each loci separated by their distances in the requested *Unit* (either Haldane (h) or Kosambi (k) for genetic data, Rays are always used for radiated hybrid data)

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Unit*: the distance function used to compute distances from recombination/breakage ratios. It is either Haldane (h) or Kosambi (k) for genetic data. Rays are always used for radiated hybrid data.
- *MapId*: the numerical Id of the map in the heap.



**Returns:** a list describing the map. See above.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 21 326}
CG> sem

Map -1 : log10-likelihood = -795.54
-----:
Set : Marker List ...
  1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...
  2 : MS4 MS5          MS6              MS8 MS7          MS3 MS9 MS15          ...

CG> mapget k 0
0 -795.54 {1 -479.22 MS4 0.0 MS5 3.3 MS13 38.8 MS6 64.2 MS11 86.4 MS17 137.9 \
MS16 159.5 MS8 186.5 MS7 192.4 MS2 207.4 MS3 208.0 MS9 231.5 MS15 249.3 MS12 \
252.8 MS20 291.1 MS19 293.8 MS1 483.9} {2 -316.32 MS4 0.0 MS5 84.4 MS6 138.5 \
MS8 229.0 MS7 307.2 MS3 493.5 MS9 706.1 MS15 862.8 MS1 1622.9 G36 1726.5 G39 \
1786.2 G37 1845.9 G40 1871.3}
```

**See also:**

- mapordget (2.4.14)
- mapprint (2.4.8)

## 2.4.14 mapordget

Returns a list describing the order of the markers in the map whose numerical Id in the heap is given.

**Synopsis:** The mapordget command is invoked either as:

- mapordget *Options*
- mapordget *MapId*

**Description:** The mapordget command returns a list that gives the order of the numerical Ids of the markers in the map whose numerical Id in the heap is given as argument.

**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *MapId*: the numerical Id of the map in the heap.

**Returns:** a list giving the order of the markers numerical Ids.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 21 326}
CG> sem

Map -1 : log10-likelihood = -795.54
-----:
Set : Marker List ...
  1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...
  2 : MS4 MS5      MS6      MS8 MS7      MS3 MS9 MS15      ...

CG> mapordget 0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
```

**See also:**

- mapget (2.4.13)
- maprint (2.4.8)

**2.4.15 mapocb**

Returns the number of Obligate Chromosome Breaks for the map whose numerical Id in the heap is given.

**Synopsis:** The mapocb command is invoked either:

- mapocb *Options*
- mapocb *MapId*

**Description:** The `mapocb` command computes the number of Obligate Chromosome Breaks for the map whose numerical Id in the heap is given as argument. For each data-set, for each individual/hybrid, for each pair of consecutive markers in the map, there is an obligate chromosome break if we have the corresponding typing data “0 1” or “1 0” (e.g. 0=Absent, 1=Here). `mapocb` returns the sum of all obligate chromosome breaks.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *MapId*: the numerical id of the map in the heap.

**Returns:** number of Obligate Chromosome Breaks.

#### Example:

```
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Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> sem

Map -1 : log10-likelihood = -1090.04
-----:
Set : Marker List ...
    1 : MS1 MS13 MS15 MS17 MS19 MS2 MS20 MS3 MS4 MS5 MS6 MS7 MS8 MS9 G1 G2 G...

CG> mapocb 0
1025
CG>
```

#### See also:

- `maprint` (2.4.8)

### 2.4.16 `heaprinto`

Displays the contents of the heap.

**Synopsis :** The CarthaGene `heaprinto` command is invoked as either one of:

- `heaprinto Options`
- `heaprinto NbMrk Blank Comp`

**Description :** `heaprinto` compares each map contained in the heap to the best current map. The position of each locus on the best map is printed at its new position on the current map. If the *NbMrk* argument is equal to 0, all the positions are printed. Otherwise, only the differences are printed. The *NbMrk* argument allows to visualize *NbMrk* consecutive differences or more with square brackets. If *Blank* argument is set to 1, the positions between the extremities of an interval are replaced by '-'. If *Comp* is set to 1, only the extremities of intervals are printed consecutively. At the end of each line, the contribution to the delta lod is printed for each data set "merged by order".

#### Arguments :

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbMrk* : The minimum number of markers needed to mention an area of change. The *NbMrk* argument must be a positive integer.
- *Blank* : The flag to choose either to print blanks (1) or to print all the positions inside a interval (0). The *Blank* argument must be set to 0 or 1.
- *Comp* : The flag to compress intervals (1) or not (0). The *Blank* argument must be set to 0 or 1.

#### Example :

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc1.cg
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsmergor 1 2
{3 merged by order 21 326}
CG> sem

Map -1 : log10-likelihood = -795.54
-----:
Set : Marker List ...
  1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 M...
  2 : MS4 MS5      MS6      MS8 MS7      MS3 MS9 MS15      ...

CG> flips 5 3.0 1
...
# To print all the positions.
CG> heaprinto 0 0 0
Loci Id .....
      :
      :                               1 1           1 1 1 1 2 2 1 ...
      : 2 4 5 3 7 6 0 1 1 9 8 2 4 3 6 0 1 8 ...
Loci Pos ..... | | | | | | | | | | | | | | | | | | ...
Map Id : log10   : | | | | | | | | | | | | | | | | | | ...
  1 : -687.60 : 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 1...
 12 :    0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 18 15 16 1...
```

```

3 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 1...
4 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 14 16 17 1...
5 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 16 17 14 1...
13 :     0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 1...
7 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 14 18 16 1...
8 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 14 16 18 1...
9 :      0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 16 14 18 1...
10 :     0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 15 16 14 17 1...
11 :     0.00 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 18 16 1...
14 :     0.19 = 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 18 20 19 1...
6 :      0.77 = 1 0 2 3 4 5 6 7 8 9 10 11 12 13 14 15 18 16 1...
2 :      0.77 = 1 0 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 1...
0 :      0.77 = 1 0 2 3 4 5 6 7 8 9 10 11 12 13 14 18 15 16 1...

```

# To see consecutive differences of length greater than 3.

CG> heaprinto 3 0 0

```

Loci Id .....
      :
      :      1 1      1 1 1 1 2 2 1 ...
      :      2 4 5 3 7 6 0 1 1 9 8 2 4 3 6 0 1 8 ...
Loci Pos ..... | | | | | | | | | | | | | | | | | | ...
Map Id : log10  : | | | | | | | | | | | | | | | | | | ...
1 : -687.60 : 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 1...
12 : 0.00 = 18[15 16 1...
3 : 0.00 = 18 1...
4 : 0.00 = 15 14 ...
5 : 0.00 = [15 16 17]14 ...
13 : 0.00 = 1...
7 : 0.00 = 15 14 18 16 1...
8 : 0.00 = 15 14 18 1...
9 : 0.00 = 15 16 14 18 1...
10 : 0.00 = 15 16 14 ...
11 : 0.00 = 18 16 1...
14 : 0.19 = 18 20 19[1...
6 : 0.77 = 1 0 18 16 1...
2 : 0.77 = 1 0 ...
0 : 0.77 = 1 0 18[15 16 1...

```

# To see the ends of the consecutive differences only.

CG> heaprinto 3 1 0

```

Loci Id .....
      :
      :      1 1      1 1 1 1 2 2 1 ...
      :      2 4 5 3 7 6 0 1 1 9 8 2 4 3 6 0 1 8 ...
Loci Pos ..... | | | | | | | | | | | | | | | | | | ...
Map Id : log10  : | | | | | | | | | | | | | | | | | | ...
1 : -687.60 : 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 1...
12 : 0.00 = 18[15 -- 1...
3 : 0.00 = 18 1...
4 : 0.00 = 15 14 ...
5 : 0.00 = [15 -- 17]14 ...
13 : 0.00 = 1...
7 : 0.00 = 15 14 18 16 1...
8 : 0.00 = 15 14 18 1...
9 : 0.00 = 15 16 14 18 1...
10 : 0.00 = 15 16 14 ...
11 : 0.00 = 18 16 1...
14 : 0.19 = 18 20 19[1...
6 : 0.77 = 1 0 18 16 1...
2 : 0.77 = 1 0 ...

```

```

0 :      0.77 = 1 0                                18[15 -- 1...

# To make the line shorter.
CG> heaprinto 3 1 1
Loci Id .....
      :
      :      1 1                                1 1 1 1 2 2 1 ...
      :      2 4 5 3 7 6 0 1 1 9 8 2 4 3 6 0 1 8 ...
Loci Pos ..... | | | | | | | | | | | | | | | | | | ...
Map Id : log10 : | | | | | | | | | | | | | | | | | | ...
1 : -687.60 : 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 1...
12 :      0.00 = 18[15 17] (      0.00 +      0.00 )
3 :      0.00 = 18 17 (      0.00 +      0.00 )
4 :      0.00 = 15 14 (      0.00 +      0.00 )
5 :      0.00 = [15 17] 14 (      0.00 +      0.00 )
13 :      0.00 = 19 18 (      0.00 +      0.00 )
7 :      0.00 = 15 14 18 16 17 (      0.00 +      0.00 )
8 :      0.00 = 15 14 18 17 (      0.00 +      0.00 )
9 :      0.00 = 15 16 14 18 17 (      0.00 +      0.00 )
10 :      0.00 = 15 16 14 (      0.00 +      0.00 )
11 :      0.00 = 18 16 17 (      0.00 +      0.00 )
14 :      0.19 = 18 20 19[17 15] (      0.00 +      0.19 )
6 :      0.77 = 1 0 18 16 17 (      1.38 +     -0.62 )
2 :      0.77 = 1 0 (      1.38 +     -0.62 )
0 :      0.77 = 1 0 18[15 17] (      1.38 +     -0.62 )

```

See also :

- `heaprint` (2.4.4)
- `heaprintd` (2.4.5)

## 2.5 Building maps from scratch

In `CARHAGENE` everything starts by building a first initial map from the current set of selected markers. This first map will be stored in the heap and will be used as the indispensable “seed” for further map improving commands. There are several methods to produce such a first map and they can be simply classified as methods that aim at providing *comprehensive* maps and methods that aim at providing *framework* maps.

- Comprehensive maps are maps that will contain all the markers mentioned in the set of currently active markers. The maps sought are typically maps whose loglikelihood is maximum in this case.
- Framework maps are maps that may contain a subset of the markers mentioned in the set of currently active markers. The aim is to select markers that can be reliably ordered (i.e., which can be ordered in such a way that all alternative orders are less likely by several orders of magnitudes).

All the initial mapping commands of `CARHAGENE` are simple heuristics commands that do not spend a large amount of time trying to build an ideal map. The consequence of this, which is true for all existing software using such “quick” mapping techniques, is that the maps produced by `CARHAGENE` may be still be improved. For this, use the “improving” commands (section 2.6).

### 2.5.1 Comprehensive mapping

The first simplest command to produce a map is the `sem` command. SEM is a shortcut for “Single EM”: it will produce a map using the current order used to specify the list of active markers (specified using the `mrkselset` command). The map parameters are automatically optimized by the EM algorithm (hence the name of the command). Naturally, unless you have some good idea of the markers ordering, this command has no reason to produce a likely map.

The next level of sophistication is provided by the `nicemapl`, `nicemapd`, `mfmapl` and `mfmaph` commands that exploit 2-points measures such as 2-points LOD and 2-points distances. A strong limitation of such commands is that often, in multiple population mapping, some 2-points measures may be undefined. this is the case eg. when a marker is typed in one population and not in another. In such case, it is likely that such commands will produce poor maps. The heuristics used to build maps is the so-called “nearest neighbor” heuristics. It consists in adding as a new marker the marker which is the closer (resp. more strongly linked) to the previous marker. The heuristics is called repeatedly starting from all possible markers and the best map produced (w.r.t. loglikelihood) is reported. There is another kind of heuristic based on the powerful Keld Helsgaun’s LKH software. LKH implements the Lin-Kernighan heuristic for solving Traveling Salesman Problems. See commands `lkh`, `lkhn`, `lkh1`, `lkhd`, `lkhocb` and `lkhocbn`. It is also possible to use another TSP solver by using the `cg2tsp` command in order to export the marker ordering problem into a TSP format. The commands `fconcorde` and `flkh` use external system calls (only on Linux computers) to William Cook’s Concorde TSP exact solver and LKH respectively.

The next level of sophistication is provided by the `build` function, inspired by similar facilities in CRIMAP [Gre88]. This command starts by examining all pairs of markers in the current list of active markers and keeps the pair that has a maximum likelihood. Then a new marker is selected: it is the markers which is the most strongly linked with markers already in the map. It is tentatively inserted in all possible positions and the best position is kept. Because this process is still far from always yielding good maps, it is typically performed on several distinct maps in parallel (the maps are the  $k$  best maps found at each step instead of just the best one). The parameter  $k$  is specified as a numerical argument to the `build` command. This command is largely superseded by the framework mapping command `buildfw` which can also perform comprehensive mapping.

### 2.5.2 `sem`

Computes the maximum likelihood of the current active markers order.

**Synopsis:** The `sem` command is invoked either as:

- `sem Options`
- `sem`

**Description:** The `sem` command (for “Single EM”) performs the maximum likelihood estimation of all the needed recombination /breakage/retention ratio parameters for the current data-set using the current marker ordering (available using the `mrkselget` command). The map obtained is submitted for the heap and is therefore memorized if it is close enough to the optimum map.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing. The map is submitted to the heap.

### Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> mrkselget
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
CG> sem

Map -1 : log10-likelihood = -291.76
-----:
Set : Marker List ...
    1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS16\
      MS17 MS18 MS19 MS20

CG>
```

### See also:

- `mrkselset` (2.3.14)

### 2.5.3 `cgtolerance`

Fixes the convergence threshold used in EM, the optimization algorithm used for multipoint recombination/breakage/retention estimation.

**Synopsis:** The `tolerance` command is invoked as either:

- `cgtolerance` *Options*
- `cgtolerance` *Fine.Threshold* *Raw.Threshold*

**Description:** The `tolerance` command sets the convergence threshold used in EM, the optimization algorithm used for multipoint recombination (genetic data), breakage and retention estimation (RH data). The EM algorithm is an iterative loglikelihood algorithm that stops iterating when the loglikelihood increases become too small, below a given threshold.

The first argument is used for final estimation. All the maps presented to the user are converged up to this threshold, initially set to 0.001. The second argument is used for raw estimation inside ordering commands. The loglikelihood is first maximized using this raw threshold (initially set to 0.1) and if it is still far from the loglikelihood of the best know map, then further iteration are abandoned. Otherwise, the iteration are continued until a final level of convergence is reached.



**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *Fine Threshold*: the final EM convergence threshold.
- *Raw Threshold*: the raw EM convergence threshold.

**Example:**

```

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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh1.cg
{1 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> sem

Map -1 : log10-likelihood = -286.91
-----:
Set : Marker List ...
1 : G36 MS5 MS6 MS7 MS9 MS8 MS1 G39 MS3 G37 MS15 G40 MS4

CG> dsload Data/rh1.cg
{2 haploid RH 13 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> cgtolerance 0.00001 0.01

CG> sem

Map -1 : log10-likelihood = -286.90
-----:
Set : Marker List ...
2 : G36 MS5 MS6 MS7 MS9 MS8 MS1 G39 MS3 G37 MS15 G40 MS4

```

**2.5.4 nicemap1**

Computes an intuitively nice marker ordering using 2-points LOD.

**Synopsis:** The `nicemap1` command is invoked as either one of :

- `nicemap1 Options`
- `nicemap1`

**Description:** The `nicemapl` command orders the current list of active markers using a simple Nearest Neighbor heuristics. Starting from each marker successively, it builds a map by always selecting the marker with the strongest LOD as the next marker. The best map according to multipoint maximum likelihood is inserted in the heap.

Warning: since 2-points estimations are typically unavailable for some pairs of markers when data-sets are merged, this command will return very poor maps on such merged data. This command should be used preferably to `nicemapd` when some data-sets have been merged with separate parameter estimation (using `mergor`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> nicemapl

Map -1 : log10-likelihood = -344.26
-----:
Set : Marker List ...
  1 : MS14 MS13 MS11 MS10 MS5 MS6 MS1 MS2 MS3 MS4 MS7 MS8 MS9 MS12 MS15 MS16\
MS17 MS18 MS19 MS20
```

**See also:**

- `sem` (2.5.2)
- `nicemapd` (2.5.5)
- `mfmapl` (2.5.6)
- `mfmapd` (2.5.7)
- `build` (2.5.16)
- `buildfw` (2.5.18)

## 2.5.5 `nicemapd`

Computes an intuitively nice marker ordering using 2-points distances.

**Synopsis:** The `nicemapd` command is invoked as either one of :

- `nicemapd Options`
- `nicemapd`

**Description:** The `nicemapd` command orders the current list of active markers using a simple Nearest Neighbor heuristics. Starting from each marker successively, it builds a map by always selecting the nearest marker. The best map according to multipoint maximum likelihood is inserted in the heap.

Warning: since 2-points estimations are typically unavailable for some pairs of markers when data-sets are merged, this command will return very poor maps on such merged data. This command should especially not be used when two data-sets have been merged with separate parameters estimation (using `mergor`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg
```

```
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
```

```
CG> nicemapd
```

```
Map -1 : log10-likelihood = -325.47
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : MS13 MS14 MS11 MS10 MS9 MS8 MS7 MS6 MS5 MS4 MS3 MS2 MS1 MS12 MS15 MS16\  
MS18 MS17 MS19 MS20
```

**See also:**

- `nicemapl` (2.5.4)
- `mixmapd` (2.5.7)
- `mixmapl` (2.5.6)
- `sem` (2.5.2)

## 2.5.6 mfmap1

Computes an intuitively nice marker ordering using 2-points LOD.

**Synopsis:** The `mfmap1` command is invoked as either one of :

- `mfmap1 Options`
- `mfmap1`

**Description:** The `mfmap1` command builds gradually a map by inserting the best (whose LOD criteria are minima) available pairs of markers among the current list of active markers. This “Greedy” heuristic applies a multi-fragment (mf) strategy: several order fragments of markers which are close together are constructed and then linked together.

Warning: since 2-points estimations are typically unavailable for some pairs of markers when data-sets are merged, this command will return very poor maps on such merged data. This command should especially not be used when two data-sets have been merged with separate parameters estimation (using `mergor`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> mfmap1

Map -1 : log10-likelihood = -348.64
-----:
Set : Marker List ...
1 : MS10 MS5 MS6 MS1 MS2 MS3 MS4 MS7 MS8 MS9 MS12 MS15 MS16 MS13 MS11 MS14\
MS17 MS18 MS19 MS20
```

**See also:**

- `mfmapd` (2.5.7)
- `nicemap1` (2.5.4)
- `nicemapd` (2.5.5)
- `sem` (2.5.2)

### 2.5.7 mfmapd

Computes an intuitively nice marker ordering using 2-points distances.

**Synopsis:** The `mfmapd` command is invoked as either one of :

- `mfmapd Options`
- `mfmapd`

**Description:** The `mfmapd` command builds gradually a map by inserting the best (whose distances are minima) available pairs of markers among the current list of active markers. This “Greedy” heuristic applies a multi-fragment (mf) strategy: several order fragments of markers which are close together are constructed and then linked together.

Warning: since 2-points estimations are typically unavailable for some pairs of markers when data-sets are merged, this command will return very poor maps on such merged data. This command should especially not be used when two data-sets have been merged with separate parameters estimation (using `mergor`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> mfmapd

Map -1 : log10-likelihood = -321.28
-----:
Set : Marker List ...
  1 : MS1 MS2 MS3 MS4 MS5 MS7 MS6 MS8 MS11 MS10 MS9 MS14 MS12 MS13 MS16 MS15\
MS17 MS18 MS19 MS20
```

**See also:**

- `mfmapl` (2.5.6)
- `nicemapd` (2.5.5)
- `nicemapl` (2.5.4)
- `sem` (2.5.2)

### 2.5.8 lkh

Computes an intuitively nice marker ordering using 2-points loglikelihoods.

**Synopsis:** The `lkh` command is invoked as either one of :

- `lkh Options`
- `lkh NbRun CollectMaps`

**Description:** The `lkh` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic. At each run, LKH tries different starting points (the number of starting points is equal to the number of markers ; if the heap was not empty, the best map in the heap is used as the first starting point, other starting points are randomly generated).
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq 0$  then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH. If set to -1, only locally optimal tours w.r.t. the LK neighborhood are inserted into the heap.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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```

```
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under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/rh.cg
```

```
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
```

```
CG> lkh 1 -1
```

```
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \  
software. If you want to use this command you must check that you are entitle\  
d to use this code (only for research use, see the README file in the LKH dir\  
ectory) and use the research version of CarthaGene(compiled with the LKHLICEN\  
CE macro defined).
```

```
Map -1 : log10-likelihood = -831.53
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : MS20 MS1 G39 MS3 MS2 G37 G40 G36 MS4 MS7 MS6 G3 G4 MS5 G1 G2 MS8 MS9 G\
```

```
21 G26 G22 G25 G23 G27 G24 G28 G34 G33 G30 G29 G31 G32 MS13 G35 G15 MS15 G14 \
G18 G17 G5 G6 G16 G13 G12 G7 G8 G11 MS19 G10 G9 G19 MS17 G20
```

CG>

**See also:**

- `lkh`n (2.5.9)
- `lkh`l (2.5.10)
- `lkh`d (2.5.11)
- `cg2tsp` (2.5.14)

## 2.5.9 `lkh`n

Computes an intuitively nice marker ordering using normalized 2-points loglikelihoods.

**Synopsis:** The `lkh`n command is invoked as either one of :

- `lkh`n *Options*
- `lkh`n *NbRun CollectMaps*

**Description:** The `lkh`n command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic.
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq 0$  then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH.

**Returns:** nothing.

### Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> lkhn 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \
software. If you want to use this command you must check that you are entitle\
d to use this code (only for research use, see the README file in the LKH dir\
ectory) and use the research version of CarthaGene(compiled with the LKHLICEN\
CE macro defined).

Map -1 : log10-likelihood = -831.53
-----:
Set : Marker List ...
1 : MS20 MS1 G39 MS3 MS2 G37 G40 G36 MS4 MS7 MS6 G3 G4 MS5 G1 G2 MS8 MS9 G\
21 G26 G22 G25 G23 G27 G24 G28 G34 G33 G30 G29 G31 G32 MS13 G35 G15 MS15 G14 \
G18 G17 G5 G6 G16 G13 G12 G7 G8 G11 MS19 G10 G9 G19 MS17 G20

CG>
```

### See also:

- `lkh` (2.5.8)
- `lkh1` (2.5.10)
- `lkhd` (2.5.11)
- `cg2tsp` (2.5.14)

## 2.5.10 `lkh1`

Computes an intuitively nice marker ordering using 2-points LOD criteria.

**Synopsis:** The `lkh1` command is invoked as either one of :

- `lkh1 Options`
- `lkh1 NbRun CollectMaps`

**Description:** The `lkh1` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.



**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic.
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq$  0 then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> lkh1 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \
software. If you want to use this command you must check that you are entitle\
d to use this code (only for research use, see the README file in the LKH dir\
ectory) and use the research version of CarthaGene(compiled with the LKHLICEN\
CE macro defined).

Map -1 : log10-likelihood = -831.53
-----:
Set : Marker List ...
1 : MS20 MS1 G39 MS3 MS2 G37 G40 G36 MS4 MS7 MS6 G3 G4 MS5 G1 G2 MS8 MS9 G\
21 G26 G22 G25 G23 G27 G24 G28 G34 G33 G30 G29 G31 G32 MS13 G35 G15 MS15 G14 \
G18 G17 G5 G6 G16 G13 G12 G7 G8 G11 MS19 G10 G9 G19 MS17 G20

CG>
```

**See also:**

- lkh (2.5.8)
- lkh1 (2.5.9)
- lkh2 (2.5.11)
- cg2tsp (2.5.14)

**2.5.11 lkh1**

Computes an intuitively nice marker ordering using 2-points distances.

**Synopsis:** The `lkhd` command is invoked as either one of :

- `lkhd Options`
- `lkhd NbRun CollectMaps`

**Description:** The `lkhd` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.

Warning: since 2-points estimations are typically unavailable for some pairs of markers when data-sets are merged, this command will return very poor maps on such merged data. This command should especially not be used when two data-sets have been merged with separate parameters estimation (using `mergor`).

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic.
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq 0$  then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh.cg  
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> lkhd 1 -1
```

```
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \  
software. If you want to use this command you must check that you are entitle\  
d to use this code (only for research use, see the README file in the LKH dir\  
ectory) and use the research version of CarthaGene(compiled with the LKHLICEN\  
CE macro defined).
```

```
Map -1 : log10-likelihood = -829.24  
-----:
```

```
Set : Marker List ...
```

```
1 : MS17 G20 G19 G9 G10 MS19 G11 G8 G7 G12 G13 G16 G6 G5 G17 G18 G14 MS15 \  
G15 G35 MS13 G32 G31 G29 G30 G33 G34 G28 G24 G27 G23 G25 G22 G26 G21 MS9 MS8 \  
G2 G1 MS5 G4 G3 MS6 MS7 MS4 G36 G40 G37 MS2 MS3 G39 MS1 MS20
```

```
CG>
```

**See also:**

- `lkh` (2.5.8)
- `lkhcn` (2.5.9)
- `lkh1` (2.5.10)
- `cg2tsp` (2.5.14)

## 2.5.12 `lkhocb`

Computes an intuitively nice marker ordering using 2-points Obligate Chromosome Breaks criterion.

**Synopsis:** The `lkhocb` command is invoked as either one of :

- `lkhocb Options`
- `lkhocb NbRun CollectMaps`

**Description:** The `lkhocb` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic.
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq$  0 then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh.cg  
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> lkhocb 1 -1  
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \  
software. If you want to use this command you must check that you are entitle\
```

d to use this code (only for research use, see the README file in the LKH dir\ectory) and use the research version of CarthaGène(compiled with the LKHLICEN\CE macro defined).

```
Map -1 : log10-likelihood = -831.53
```

```
-----;
```

```
Set : Marker List ...
```

```
1 : MS20 MS1 G39 MS3 MS2 G37 G40 G36 MS4 MS7 MS6 G3 G4 MS5 G1 G2 MS8 MS9 G\
21 G26 G22 G25 G23 G27 G24 G28 G34 G33 G30 G29 G31 G32 MS13 G35 G15 MS15 G14 \
G18 G17 G5 G6 G16 G13 G12 G7 G8 G11 MS19 G10 G9 G19 MS17 G20
```

```
CG>
```

#### See also:

- `lkhocbn` (2.5.13)
- `lkh` (2.5.8)
- `cg2tsp` (2.5.14)

### 2.5.13 `lkhocbn`

Computes an intuitively nice marker ordering using normalized 2-points Obligate Chromosome Breaks criterion.

**Synopsis:** The `lkhocbn` command is invoked as either one of :

- `lkhocbn Options`
- `lkhocbn NbRun CollectMaps`

**Description:** The `lkhocbn` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using Keld Helsgaun's LKH software. LKH is based on the Lin-Kernighan heuristic. It is possible to collect every tour found by LKH into the CarthaGene heap, in order to get a map with a possible better multipoint loglikelihood.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbRun* : Repeats *NbRun* times the LK heuristic.
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps*  $\neq$  0 then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH.

**Returns:** nothing.

### Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> lkhocbn 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TSP \
software. If you want to use this command you must check that you are entitle\
d to use this code (only for research use, see the README file in the LKH dir\
ectory) and use the research version of CarthaGene(compiled with the LKHLICEN\
CE macro defined).

Map -1 : log10-likelihood = -831.53
-----:
Set : Marker List ...
1 : MS20 MS1 G39 MS3 MS2 G37 G40 G36 MS4 MS7 MS6 G3 G4 MS5 G1 G2 MS8 MS9 G\
21 G26 G22 G25 G23 G27 G24 G28 G34 G33 G30 G29 G31 G32 MS13 G35 G15 MS15 G14 \
G18 G17 G5 G6 G16 G13 G12 G7 G8 G11 MS19 G10 G9 G19 MS17 G20

CG>
```

### See also:

- lkhocb (2.5.12)
- lkh (2.5.8)
- cg2tsp (2.5.14)

## 2.5.14 cg2tsp

Convert current marker selection to TSP.

**Synopsis:** The `cg2tsp` command is invoked either as:

- `cg2tsp Options`
- `cg2tsp FileName`

**Description:** The `cg2tsp` command converts the current marker selection and associated genetic / radiated hybrid data into different traveling salesman problems, one for each available criterion. Each file name is a concatenation of a prefix and the *FileName* parameter. The prefix can be: an empty string for 2-points loglikelihoods, *norm* for normalized 2-points loglikelihoods, *dist* for 2-points distances, *lod* for 2-points LOD criteria, *min* for minimum 2-points loglikelihoods, *max* for maximum 2-points loglikelihoods. Resulting files are in the TSPLIB file format.

**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *FileName*: the suffix name of the TSP files.

**Example:**

```
...
CG> dsload Data/rh.cg
CG> cg2tsp rh.tsp
...
```

**See also:**

- lkh (2.5.8)
- lkhn (2.5.9)
- lkh1 (2.5.10)
- lkhd (2.5.11)

**2.5.15 fconcorde**

Computes an intuitively nice marker ordering using 2-points loglikelihoods.

**Synopsis:** The `fconcorde` command is invoked without any parameters.

**Description:** The `fconcorde` command converts the current marker selection and associated genetic / Radiated Hybrid data into a Traveling Salesman Problem which is solved using William Cook's Concorde software. Concorde is an exact method which always returns the optimum. An executable file `concorde` must be made accessible in your `PATH` Linux environment variable.

**No arguments** .

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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```

Type 'help' for help.

```
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
```

```

CG> fconcorde
All TSP costs multiplied by 1000.
TSP: optimum= 801.055 bbnodes= 1 totaltime= 0.06 sec.
and, in multi-points:

Map -1 : log10-likelihood = -822.89
-----:
Set : Marker List ...
  1 : MS1 G39 MS3 MS2 G37 G40 G36 MS4 G3 G4 MS5 G1 G2 MS6 MS7 MS9 MS8 G21 G2\
  6 G22 G25 G23 G27 G24 G28 G34 G33 G30 G31 G29 G32 G35 MS13 MS20 G10 G9 MS19 G\
 19 MS17 G20 G11 G8 G7 G12 G13 G16 G6 G5 G17 G18 G14 MS15 G15

CG>

CG>

```

#### See also:

- `fconcorden` (similar to 2.5.9)
- `fconcorded` (similar to 2.5.11)
- `fconcordeocb` (similar to 2.5.12)
- `fconcordeocbn` (similar to 2.5.13)

## 2.5.16 build

This command is obsolete. It is largely superseded by the `buildfw` command which may also build comprehensive maps. It heuristically builds a relatively good comprehensive map using an incremental insertion procedure.

**Synopsis:** The CarthaGene `build` command is invoked as either one of :

- `build Options`
- `build NbMap`

**Description :** starting from the most tightly connected (maximum 2 points LOD) pair of markers, the loci whose mean LOD with already inserted markers is maximum is inserted at its best position. Actually, all best *NbMap* insertion points are kept. The process is repeated for all markers.

#### Arguments :

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbMap*: the number of candidate maps kept at each iteration.

**Returns:** nothing but all maps explored are candidate for the heap.

### Example :

```
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under certain conditions. See the License file for information.

Type 'help' for help.

# we first load a data set
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
# we perform group detection (output omitted)
CG> group 0.3 3
...
# we select group 10
CG> mrkselset [groupget 10]

# we use the command build (20 parallel maps)
CG> build 20

Build(20) : |||||

Map 14 : log10-likelihood = -141.81
-----:
Set : Marker List ...
1 : G7 G12 G13 G16 G6 G5 G17 G18 G14

# and check the quality of the final map
CG> flips 9 0 0

Single Flip(window size : 9, threshold : 0.00).

Map -1 : log10-likelihood = -141.81
-----:
Set : Marker List ...
1 : G7 G12 G13 G16 G6 G5 G17 G18 G14

2 2 2 3 2 1 3 3 2 log10
1 6 7 0 0 9 1 2 8 -141.81
[8 7 6 5 - 3 2 1 0] 0.00

# it should be Ok.
```

### See also:

- [buildfw \(2.5.18\)](#)
- [nicemapl \(2.5.4\)](#)
- [nicemapd \(2.5.5\)](#)
- [mfmapl \(2.5.6\)](#)



- `mfmapped` (2.5.7)

### 2.5.17 Framework mapping

There is only one command in `CARTHAGENE` to perform initial framework mapping but it is quite powerful. It is the `buildfw` command and it may also perform comprehensive mapping. The command automatically select a subset of the current set of active markers and orders them. The aim is to build a map such that no alternative order of the selected markers has a loglikelihood within a given threshold of the loglikelihood of the map.

The procedure used to tackle this difficult problem is heuristics and is inspired from similar functionalities in `RHMAP` [LBLC95] and `CRIMAP` [Gre88]. It uses an incremental insertion method, trying to insert available markers in a current map. For a given marker that could be inserted, it tries to insert the marker at all possible position of the map. The difference in loglikelihood between the best insertion and the second best insertion is used to qualify the marker. The marker inserted in practice is the marker that maximizes this difference and such that this difference is larger than a first threshold (called the “Adding Threshold”). The marker is inserted at its optimal position. If there are orders whose difference in loglikelihood with this best position is less than a second threshold (called the “Keep Threshold”), they are also kept as possible new starting points for the next marker to be inserted. This threshold must naturally be equal to or larger than the adding threshold.

The build process may start from an empty map or from an existing order (in this case, it must contain at least 3 markers). When the starting map is empty, all triplets are considered as candidates and only the best triplet according to the difference in loglikelihood between the best order and the second best order is used. Otherwise, the initial order specified is used directly.

After a map is built, using this process, some postprocessing can be applied optionally: all remaining non insertable markers are inserted one by one, in all possible positions in the final map and then removed. For each such marker, the command reports how the loglikelihood changes wrt to the best insertion point. The best position is marked with a “+”. The difference in loglikelihood between the best position and each position are printed out if this difference is less than a threshold.

It is important to note that whatever the threshold you specify, this procedure may easily be fooled and the final map produced will not really be true framework map (i.e., a map such that all alternative orders have a difference in loglikelihood with the initial map larger than the “adding threshold”). This is not a weakness of `CARTHAGENE` but a weakness of all simple heuristics procedure. To be more confident about the quality of your maps, it is strongly advised to apply improving commands to it and analyse the heap to check that no close alternative order appears in it.

Alternatively, there are other framework mapping commands `frameworkmst` and `framework` which ensure a guaranteed minimum distance between the framework map and any other map with the same markers in (normalized) 2-point likelihood.

### 2.5.18 `buildfw`

Tries to heuristically build a good framework map, i.e., a map such that all alternatives orders have a loglikelihood not within a given threshold of the framework map. The command may also be used to build comprehensive maps (including all markers) by adjusting thresholds.

**Synopsis :** The `CarthaGene buildfw` command is invoked as either one of :

- `buildfw Options`
- `buildfw keepThres AddThres MrkList MrkTest`

Then, each available locus is tentatively inserted at each possible position. If there is no locus that provides a difference in log-likelihood larger than the *AddThres* threshold, the algorithm stops. If there are many orders for which the difference of log-likelihood is larger than the *KeepThres* Threshold, they are kept for the next step. The *MrkTest* flag indicates if post-processing is applied. If it is set to 0 no post-processing occurs. If it is set to 1, each remaining locus is tentatively inserted at each position in the previously built framework map and the difference in log-likelihood between each possible insertion and the best one (denoted by a '+') is reported. If it set to 2, no framework is built in the previous stage, instead the *MrkList* list of loci is used and the same post-processing as above applies. If the *MrkTest* equals 0 or 1, the framework's markers become the list of currently active markers.

BuildFW, remaining loci test :

									Lod2pt	Dist2pt								
	1	2	3	4	5	6	7	8	Left<-M->Right	Left<-M->Right	0->N	N->M	Weight	Nb:W<AM	Id		Name	
M1702								+ 0	2.16	23.97	115.1	2.5	680.8	106.7	0	2	9	M1702

- the first group of columns displays the name of the marker that has been tentatively inserted (M1702 above)
- the second group of columns displays the result of inserting this marker in the framework map. The best possible insertion position is reported by a “+”. When alternative insertion positions exists with a small difference in log-likelihood (less than *KeepThres*), they are also reported by the nearest integer that represents this difference (eg “0” above corresponds to a difference in log-likelihood between in  $[0, 0.5]$ ).

When merged datasets are used, the two-points distances reported are computed only on informative data-sets and averaged among the informative data-sets. When RH data is used, and because different irradiation level (or mixed RH/genetic data) may have been used, distances are not averaged: only the first dataset merged is used.

- the 5<sup>th</sup> group of columns successively reports:

- *Weight*: the sum of the difference of log-likelihood with the best map for all maps within *KeepThres* of the best map. A large weight indicates a marker whose position is not well defined.
  - *Nb:W<AM*: the number of insertion position where the difference in log-likelihood exceeds *KeepThres*.
  - *Id*: the marker numerical Id.
- the last column gives the name of the inserted marker again (same as first column).

### Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *KeepThres*: the minimum difference in log-likelihood between the best insertion point and the second best insertion point required for the map to be considered in the future.
- *AddThres*: the minimum difference in log-likelihood between the best insertion point and the second best insertion point required for a locus to be insertable. This threshold is also used to filter out the differences in log-likelihood reported by the postprocessing option (only differences lower than the threshold will be reported).
- *MrkList*: an order of markers to start from (may be empty or contain at least 3 markers).
- *MrkTest*: a flag to select either framework mapping only (0), framework mapping followed by a postprocessing (1) or just the post-processing applied to (2)*MrkList*.

**Returns :** nothing but the set of active markers is automatically set to the framework map built if the *MrkTest* equal 0 or 1, not 2.

### Example :

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CarthaGene comes with ABSOLUTELY NO WARRANTY.

CarthaGene is free software. You are welcome to redistribute it, under certain conditions. See the License file for information.

Type 'help' for help.

```
# we first load a data set
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
# we perform linkage group detection (output omitted)
CG> group 0.3 3
...
# we select the group 10
CG> mrkselset [groupget 10]

# we build a framework map for this group
CG> buildfw 3 3 {} 1
```

BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.

```

>>> Delta = 6.89 :

Map 0 : log10-likelihood = -66.75
-----:
Set : Marker List ...
    1 : G7 G12 G16

>>> Delta = 6.30 , Id = 32, Locus = G18 :

Map 0 : log10-likelihood = -80.72
-----:
Set : Marker List ...
    1 : G7 G12 G16 G18

>>> Delta = 7.04 , Id = 28, Locus = G14 :

Map 0 : log10-likelihood = -93.15
-----:
Set : Marker List ...
    1 : G7 G12 G16 G18 G14

BuildFW, remaining loci test :
      |      |
      | 2 2 3 3 2 |      Lod2pt      Dist2pt
      | 1 6 0 2 8 |      Left<-M->Right Left<-M->Right | 0->N      N->M | Weigh...
      |-----|-----|-----|-----|-----|
G5 |      3 1 + | 13.70      -      29.6      -      | 91.9  29.6 | 4...
G17 |      2 + 0 | 18.05  15.66  21.1  25.3 | 72.0  9.0 | 2...
G13 |      + 3   | 20.41  22.03  14.6  10.6 | 30.4  12.7 | 3...
G6  |      + 0   | 16.23  20.68  25.7  14.6 | 30.4  14.0 | 0...

# and check its reliability (any map at less than 3 LOD ?)
CG> flips 4 3 0

Single Flip(window size : 4, threshold : 3.00).

Map -1 : log10-likelihood = -93.15
-----:
Set : Marker List ...
    1 : G7 G12 G16 G18 G14

2 2 3 3 2 log10
1 6 0 2 8 -93.15

# no.

```

#### See also:

- [build \(2.5.16\)](#)
- [heaprinto \(2.4.16\)](#)
- [cgrobustness \(2.5.19\)](#)

### 2.5.19 cgrobustness

Sets the reliability testing threshold for framework maps.

**Synopsis:** The `cgrobustness` command is invoked as either:

- `cgrobustness Options`
- `cgrobustness Threshold`

**Description:** The `cgrobustness` command sets the threshold used to verify if the current best known map is robust or not. A map  $M$  is not robust if there exists another map  $M'$  such that  $L(M') > L(M) + \delta$ , where  $L(M)$  is the multipoint log-likelihood of  $M$ . A common value for the threshold  $\delta$  is  $-3.0$ . When robustness checking is activated, each time a new map is inserted into the heap, the system verifies if the current best map is still robust. If not then it will stop any running search procedure because it has found a proof that the best known map is not robust enough. This is typically used when checking the reliability of a framework map using a cpu-intensive command such as `flips` or `greedy` in order to stop the search process as soon as the unreliability is proven.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Threshold*: minimum log likelihood distance to the current best map.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> buildfw 3 3 {} 1

BuildFW, Adding Threshold = 3.00, Saving Threshold = 3.00.

>>> Delta = 46.28 :

Map 0 : log10-likelihood = -14.70
-----:
Set : Marker List ...
    1 : MS8 MS10 MS14

BuildFW, remaining loci test :
      |      |
      |  1 1  |      Lod2pt      Dist2pt
      |  8 0 4  | Left<-M->Right Left<-M->Right | 0->N      N->M | Weight Nb...
      |--|-----|-----|-----|-----|-----|-----|-----|-----|
```

MS1	2	2	+		-0.00	-	345.4	-		15.5	345.4		4	...	
MS2	+	3	2		-	15.26	-	23.8		-	23.8		5	...	
MS3	+		3		-	15.07	-	25.5		-	25.5		3	...	
MS4	+	1	2	3		-	22.84	-	14.5		-	14.5		6	...
MS5		+	1	2		12.33	4.02	14.2	5.6		0.0	2.3		3	...
MS6		3	1	+		1.05	-	22.6	-		15.5	22.6		4	...
MS7	2	+	1	3		35.05	5.05	5.7	10.8		0.0	1.1		6	...
MS9		+	0	1		40.82	7.22	1.9	0.0		0.0	3.3		1	...
MS11		1	0	+		3.61	-	0.0	-		15.5	0.0		1	...
MS12		2	0	+		3.61	-	0.0	-		15.5	0.0		2	...
MS13			0	+		6.02	-	0.0	-		15.5	0.0		0	...
MS15		3	0	+		0.00	-	345.4	-		15.5	345.4		3	...
MS16		2	0	+		3.61	-	0.0	-		15.5	0.0		2	...
MS17			+	0		1.09	1.51	31.8	0.0		3.3	12.2		0	...
MS18			2	+		0.00	-	345.4	-		15.5	345.4		2	...
MS19	1		3	+		0.45	-	34.7	-		15.5	34.7		4	...
MS20			3	+		0.71	-	45.8	-		15.5	45.8		3	...

CG> cgrobustness -5

CG> greedy 1 0 1 20 0

Map -1 : log10-likelihood = -14.70

-----:

Set : Marker List ...

1 : MS8 MS10 MS14

Run number 0

Current best map is not robust!

Aborted!

CG> heapsize 3

CG> heapprint

Map 0 : log10-likelihood = -60.98

-----:

Set : Marker List ...

1 : MS10 MS8 MS14

Map 1 : log10-likelihood = -17.48

-----:

Set : Marker List ...

1 : MS8 MS14 MS10

Map 2 : log10-likelihood = -14.70

-----:

Set : Marker List ...

1 : MS8 MS10 MS14

CG>

## See also:

- cgnotrobust (2.5.20)

### 2.5.20 cgnotrobust

Disable reliability test of framework maps.

**Synopsis:** The `cgnotrobust` command is invoked as either:

- `cgnotrobust Options`
- `cgnotrobust`

**Description:** The `cgnotrobust` command disables the reliability test of framework maps. It is equivalent to call `cgrobustness` with *Threshold* equal to 1e100.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**See also:**

- `cgrobustness` (2.5.19)

### 2.5.21 frameworkmst

Builds a framework map (only on Linux computers).

**Synopsis :** The CarthaGene `frameworkmst` command is invoked as either one of :

- `frameworkmst Options`
- `frameworkmst Delta ChangeSel`

**Description :** The `frameworkmst` command builds a framework map by selecting a subset of the current markers based on constrained maximum spanning tree algorithm. The robustness of the resulting map is controlled by the parameter *Delta*. It ensures that it does not exist any other map containing the same set of markers and with a different order such that its 2-pt log10-likelihood is greater than the framework map likelihood minus *Delta*. For instance if *Delta* is equal to 3, then any other map is 1000 less likely. If *ChangeSel* is equal to 1 then the best framework map is inserted into the Carthagene heap.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Delta*: the minimum difference in log-likelihood between the framework map and any other map with the same marker selection.
- *ChangeSel*: if equal to 1 then the best framework map is inserted into the Carthagene heap (modifying the current marker list).

**Returns :** nothing.

### Example :

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under certain conditions. See the License file for information.

Type 'help' for help.

```
CG> dsload Data/rh02_true.id
{1 haploid RH 427 88 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG>
```

```
# merge markers with similar RH vectors
```

```
CG> mrkmerges
```

```
Markers 368 and 374 merged in 368.
```

```
Markers 369 and 368 merged in 369.
```

```
Markers 348 and 354 merged in 348.
```

```
Markers 349 and 351 merged in 349.
```

```
Markers 346 and 347 merged in 346.
```

```
Markers 367 and 370 merged in 367.
```

```
Markers 358 and 359 merged in 358.
```

```
Markers 350 and 352 merged in 350.
```

```
Markers 372 and 373 merged in 372.
```

```
Markers 375 and 380 merged in 375.
```

```
Markers 288 and 290 merged in 288.
```

```
Markers 295 and 296 merged in 295.
```

```
Markers 284 and 289 merged in 284.
```

```
Markers 249 and 250 merged in 249.
```

```
Markers 255 and 257 merged in 255.
```

```
Markers 258 and 260 merged in 258.
```

```
Markers 195 and 197 merged in 195.
```

```
Markers 214 and 217 merged in 214.
```

```
Markers 238 and 241 merged in 238.
```

```
Markers 229 and 230 merged in 229.
```

```
Markers 227 and 228 merged in 227.
```

```
Markers 186 and 187 merged in 186.
```

```
Markers 127 and 132 merged in 127.
```

```
Markers 127 and 133 merged in 127.
```

```
Markers 127 and 129 merged in 127.
```

```
Markers 125 and 127 merged in 125.
```

```
Markers 91 and 95 merged in 91.
```

```
Markers 94 and 91 merged in 94.
```

```
The two markers are incompatibles.
```

```
Markers 126 and 128 merged in 126.
```

```
Markers 126 and 131 merged in 126.
```

```
Markers 126 and 134 merged in 126.
```

```
Markers 150 and 153 merged in 150.
```

```
Markers 152 and 150 merged in 152.
```

```
Markers 144 and 145 merged in 144.
```

```
The two markers are incompatibles.
```

```
Markers 141 and 142 merged in 141.
```

```
Markers 79 and 80 merged in 79.
```

```
Markers 14 and 16 merged in 14.
```

```
Markers 110 and 111 merged in 110.
```

```
Markers 110 and 112 merged in 110.
```

```
Markers 117 and 118 merged in 117.
```



Markers 117 and 121 merged in 117.  
Markers 116 and 117 merged in 116.  
Markers 3 and 390 merged in 3.  
Markers 3 and 391 merged in 3.  
Markers 3 and 392 merged in 3.  
Markers 3 and 399 merged in 3.  
Markers 3 and 400 merged in 3.  
Markers 3 and 401 merged in 3.  
Markers 3 and 402 merged in 3.  
Markers 3 and 403 merged in 3.  
Markers 3 and 404 merged in 3.  
Markers 3 and 405 merged in 3.  
Markers 3 and 395 merged in 3.  
Markers 3 and 393 merged in 3.  
Markers 3 and 397 merged in 3.  
Markers 3 and 396 merged in 3.  
Markers 146 and 149 merged in 146.  
Markers 155 and 156 merged in 155.  
Markers 155 and 157 merged in 155.  
Markers 169 and 171 merged in 169.  
Markers 176 and 177 merged in 176.  
Markers 164 and 165 merged in 164.  
Markers 411 and 412 merged in 411.  
Markers 416 and 417 merged in 416.  
Markers 426 and 427 merged in 426.  
Markers 421 and 425 merged in 421.  
Markers 410 and 414 merged in 410.  
Markers 376 and 382 merged in 376.  
Markers 376 and 378 merged in 376.  
The two markers are incompatibles.  
Markers 375 and 381 merged in 375.  
The two markers are incompatibles.  
Markers 384 and 385 merged in 384.  
The two markers are incompatibles.  
Markers 188 and 189 merged in 188.  
Markers 178 and 181 merged in 178.  
Markers 180 and 178 merged in 180.  
Markers 315 and 316 merged in 315.  
Markers 315 and 322 merged in 315.  
Markers 315 and 321 merged in 315.  
Markers 315 and 317 merged in 315.  
Markers 315 and 319 merged in 315.  
Markers 343 and 344 merged in 343.  
Markers 318 and 323 merged in 318.  
The two markers are incompatibles.  
The two markers are incompatibles.  
Markers 340 and 342 merged in 340.  
Markers 345 and 346 merged in 345.  
Markers 324 and 325 merged in 324.  
Markers 331 and 332 merged in 331.  
The two markers are incompatibles.  
Markers 326 and 327 merged in 326.  
Markers 194 and 195 merged in 194.  
Markers 279 and 280 merged in 279.  
Markers 265 and 269 merged in 265.  
Markers 265 and 266 merged in 265.  
Markers 263 and 264 merged in 263.  
Markers 265 and 271 merged in 265.

```

Markers 275 and 276 merged in 275.
Markers 245 and 249 merged in 245.
Markers 283 and 284 merged in 283.
Markers 267 and 268 merged in 267.

CG>

# build a framework map such that any other map is 100 less likely
# and update the current marker selection to this framework map
CG> frameworkmst 2 1
All TSP costs multiplied by 1000.
0 (111): 12 8 7 33 34 30 31 27 23 21 19 14 4 47 53 60 61 63 68 69 72 65 73 ...

Map -1 : log10-likelihood = -595.27
-----:
Set : Marker List ...
    1 : 12 8 7 33 34 30 31 27 23 21 19 14 4 47 53 60 61 63 68 69 72 65 73 79...

CG>

```

#### See also:

- `frameworkmst` (uses **normalized** 2-pt log10-likelihood)
- `framework` (2.5.22)

### 2.5.22 **framework**

Builds a framework map (only on Linux computers).

**Synopsis :** The CarthaGene `framework` command is invoked as either one of :

- `framework Options`
- `framework ThresholdMin ThresholdMax Delta ChangeSel`

**Description :** The `framework` command builds a framework map by selecting a subset of the current markers based on constrained all-pairs shortest path algorithm. Two adjacent markers in the framework map have their contribution to the 2-pt log10-likelihood of the map lower than a threshold the value of which varies in the range [*ThresholdMin*,*ThresholdMax*]. The robustness of the resulting map is controlled by the parameter *Delta*. It ensures that it does not exist any other map containing the same set of markers and with a different order such that its 2-pt log10-likelihood is greater than the framework map likelihood minus *Delta*. For instance if *Delta* is equal to 3, then any other map is 1000 less likely. If *ChangeSel* is equal to 1 then the best framework map is inserted into the Carthogene heap.

#### Arguments :

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *ThresholdMin*: the minimum threshold in log-likelihood for considering 2 adjacent markers.

- *ThresholdMax*: the maximum threshold in log-likelihood for considering 2 adjacent markers.
- *Delta*: the minimum difference in log-likelihood between the framework map and any other map with the same marker selection.
- *ChangeSel*: if equal to 1 then the best framework map is inserted into the Carthagene heap (modifying the current marker list).

**Returns :** nothing.

### Example :

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh02_true.id  
{1 haploid RH 427 88 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG>
```

```
# merge markers with similar RH vectors
```

```
CG> mrkmerges
```

```
Markers 368 and 374 merged in 368.
```

```
Markers 369 and 368 merged in 369.
```

```
Markers 348 and 354 merged in 348.
```

```
Markers 349 and 351 merged in 349.
```

```
Markers 346 and 347 merged in 346.
```

```
Markers 367 and 370 merged in 367.
```

```
Markers 358 and 359 merged in 358.
```

```
Markers 350 and 352 merged in 350.
```

```
Markers 372 and 373 merged in 372.
```

```
Markers 375 and 380 merged in 375.
```

```
Markers 288 and 290 merged in 288.
```

```
Markers 295 and 296 merged in 295.
```

```
Markers 284 and 289 merged in 284.
```

```
Markers 249 and 250 merged in 249.
```

```
Markers 255 and 257 merged in 255.
```

```
Markers 258 and 260 merged in 258.
```

```
Markers 195 and 197 merged in 195.
```

```
Markers 214 and 217 merged in 214.
```

```
Markers 238 and 241 merged in 238.
```

```
Markers 229 and 230 merged in 229.
```

```
Markers 227 and 228 merged in 227.
```

```
Markers 186 and 187 merged in 186.
```

```
Markers 127 and 132 merged in 127.
```

```
Markers 127 and 133 merged in 127.
```

```
Markers 127 and 129 merged in 127.
```

```
Markers 125 and 127 merged in 125.
```

```
Markers 91 and 95 merged in 91.
```

```
Markers 94 and 91 merged in 94.
```

```
The two markers are incompatibles.
```

```
Markers 126 and 128 merged in 126.
```

Markers 126 and 131 merged in 126.  
 Markers 126 and 134 merged in 126.  
 Markers 150 and 153 merged in 150.  
 Markers 152 and 150 merged in 152.  
 Markers 144 and 145 merged in 144.  
 The two markers are incompatibles.  
 Markers 141 and 142 merged in 141.  
 Markers 79 and 80 merged in 79.  
 Markers 14 and 16 merged in 14.  
 Markers 110 and 111 merged in 110.  
 Markers 110 and 112 merged in 110.  
 Markers 117 and 118 merged in 117.  
 Markers 117 and 121 merged in 117.  
 Markers 116 and 117 merged in 116.  
 Markers 3 and 390 merged in 3.  
 Markers 3 and 391 merged in 3.  
 Markers 3 and 392 merged in 3.  
 Markers 3 and 399 merged in 3.  
 Markers 3 and 400 merged in 3.  
 Markers 3 and 401 merged in 3.  
 Markers 3 and 402 merged in 3.  
 Markers 3 and 403 merged in 3.  
 Markers 3 and 404 merged in 3.  
 Markers 3 and 405 merged in 3.  
 Markers 3 and 395 merged in 3.  
 Markers 3 and 393 merged in 3.  
 Markers 3 and 397 merged in 3.  
 Markers 3 and 396 merged in 3.  
 Markers 146 and 149 merged in 146.  
 Markers 155 and 156 merged in 155.  
 Markers 155 and 157 merged in 155.  
 Markers 169 and 171 merged in 169.  
 Markers 176 and 177 merged in 176.  
 Markers 164 and 165 merged in 164.  
 Markers 411 and 412 merged in 411.  
 Markers 416 and 417 merged in 416.  
 Markers 426 and 427 merged in 426.  
 Markers 421 and 425 merged in 421.  
 Markers 410 and 414 merged in 410.  
 Markers 376 and 382 merged in 376.  
 Markers 376 and 378 merged in 376.  
 The two markers are incompatibles.  
 Markers 375 and 381 merged in 375.  
 The two markers are incompatibles.  
 Markers 384 and 385 merged in 384.  
 The two markers are incompatibles.  
 Markers 188 and 189 merged in 188.  
 Markers 178 and 181 merged in 178.  
 Markers 180 and 178 merged in 180.  
 Markers 315 and 316 merged in 315.  
 Markers 315 and 322 merged in 315.  
 Markers 315 and 321 merged in 315.  
 Markers 315 and 317 merged in 315.  
 Markers 315 and 319 merged in 315.  
 Markers 343 and 344 merged in 343.  
 Markers 318 and 323 merged in 318.  
 The two markers are incompatibles.  
 The two markers are incompatibles.

```

Markers 340 and 342 merged in 340.
Markers 345 and 346 merged in 345.
Markers 324 and 325 merged in 324.
Markers 331 and 332 merged in 331.
The two markers are incompatibles.
Markers 326 and 327 merged in 326.
Markers 194 and 195 merged in 194.
Markers 279 and 280 merged in 279.
Markers 265 and 269 merged in 265.
Markers 265 and 266 merged in 265.
Markers 263 and 264 merged in 263.
Markers 265 and 271 merged in 265.
Markers 275 and 276 merged in 275.
Markers 245 and 249 merged in 245.
Markers 283 and 284 merged in 283.
Markers 267 and 268 merged in 267.

```

```
CG>
```

```

# build a framework map such that any other map is 100 less likely
# and update the current marker selection to this framework map
CG> frameworkn 3 15 2 1
All TSP costs multiplied by 1000.
3 (2): 124 130
4 (14): 298 302 301 303 304 305 307 311 310 315 324 328 329 326
5 (14): 298 302 301 303 304 305 307 311 310 315 324 328 329 326
6 (26): 297 295 300 301 307 310 315 324 2 334 335 339 343 348 355 360 366 3...
7 (32): 160 159 158 151 143 141 137 136 135 174 168 167 179 182 183 185 188...
8 (24): 160 168 169 172 180 183 190 200 199 201 208 209 212 219 229 239 244...
9 (36): 1 424 411 407 398 386 379 369 358 340 336 2 314 304 300 299 292 291...
10 (2): 83 423
11 (28): 1 386 379 366 365 337 329 315 291 287 265 258 242 210 201 199 194 ...
12 (22): 77 164 169 182 185 192 199 220 251 259 262 288 297 301 324 334 337...
13 (27): 44 23 20 4 46 51 57 64 67 69 71 75 73 82 83 87 99 103 216 244 259 ...
14 (2): 49 363
15 (2): 44 67

Map -1 : log10-likelihood = -297.89
-----;
Set : Marker List ...
1 : 1 424 411 407 398 386 379 369 358 340 336 2 314 304 300 299 292 291 ...

```

```
CG>
```

### See also:

- `frameworkn` (uses **normalized** 2-pt log10-likelihood)
- `frameworkl` (uses 2-pt **LOD** instead of 2-pt log10-likelihood)
- `frameworkmst` (2.5.21)

## 2.6 Improving and validating existing maps

Map improving and validating commands all try to find a map whose loglikelihood is improved over an initial map. For all such commands, the initial map used is the best map in the heap. Beyond a possible map improvement, all these commands may affect the contents of the heap: all maps considered by these commands are candidate for insertion.

The first category of commands are simple heuristics command that slightly perturbate the initial map in a systematic manner:

- The famous `flips` command applies all possible permutations in a sliding window of fixed size on the initial map. The command reports all maps found whose loglikelihood lies within a given threshold of the loglikelihood of the original map. If a new improved map is found, the command may be automatically iterated. It can also be used to explore all possible orders when a small number of markers is selected by choosing a window size equal to the number of markers.
- the `polish` command removes one marker of the initial map and tries to insert it in all possible intervals. The variation in loglikelihood is reported for all markers and all positions in a matrix.
- the `squeeze` command tries to detect and remove erroneous markers such that their removal corresponds to a large reduction in the total size of the initial map.

These commands are simple and systematic. `CARTAGENE` offers much more powerful commands that use a class of discrete optimization techniques called “stochastic optimization” or more precisely “local search methods”. This class of methods is usually acknowledged as the most efficient class of technique for hard discrete optimisation problems such as the genetic marker ordering<sup>2</sup>

These optimisation methods all follow a similar principle: one or several current orders are stochastically “perturbated” and depending on the result of the perturbation and a random choice, the perturbated maps may replace the original maps or not. Three such methods are integrated in `CARTAGENE`: simulated annealing [LA84], taboo search [Glo89, Glo90] and genetic algorithm [Gol89]. The three methods use the same perturbation mechanism: a subsection of the map is chosen and flipped<sup>3</sup>. Simulated annealing and the genetic algorithm may also use more complex perturbation techniques.

Moreover, it is possible to assess the robustness of a given map by looking at the map distribution using Markov Chain Monte Carlo. For that, see the `mcmc` command. It works only in the comparative mapping approach.

These commands described next can take a long time to improve or not the current solution. The system does not provide a prediction of the time cost of this algorithms. Nevertheless, these methods can be interrupted online, without loss of information (see section 2.6.11).

### 2.6.1 Simulated annealing

The `annealing` command simulates the annealing of a metal using an analogy between the energy of the system and the criterion minimized (the opposite of the loglikelihood). Given an initial marker ordering and a current parameter called the “temperature” (noted  $T$ ), the map is perturbated and the difference  $\delta$  in loglikelihood is computed:

- if the loglikelihood is improved ( $\delta \geq 0$ ), the perturbation is accepted and the perturbated map becomes the new map.
- else, the perturbated is accepted only with probability  $e^{\frac{\delta}{T}}$ . This simulated the Boltzman distribution used in statistical physics.

---

<sup>2</sup>Which is closely related to the so-called travelling salesman problem, an NP-hard problem.

<sup>3</sup>This is called a 2-OPT move

Starting from an initial temperature  $T_i$ , this process is repeated a given number of times (noted  $N$ ). then the temperature is cooled by a constant ratio  $\alpha < 1$ . This process is repeated until a final temperature  $T_f$  is reached. Naturally, the slower the cooling and the larger the number of trial at constant temperature, the slower the method but also the more powerful it is. Basically, we strongly advise users to play with the parameters  $T_i, T_f, \alpha, N$  on their data. CAR<sub>H</sub>AGENE includes an auto-adjusting methods for  $T_i$  which makes the parameter of limited importance. The parameter  $\alpha$  should be taken close to 1 and a value between 0.9 and 0.995 is typical. The parameter  $N$  should be of the same order as  $n^2$  where  $n$  is the number of markers selected.

The parameters should be adjusted by trial and error. When the simulated annealing is executed, the software reports its behavior. If a new improved map is found, a '+' is printed. If such an event occurs not too long before the end of the annealing, the process should be ideally repeated with a slower/longer cooling schedule.

### 2.6.2 Taboo search

The `greedy` command uses a taboo search technique. Starting from an initial map, all the possible maps that can be obtained from the initial map by flipping a subsection of the map are built and their maximum loglikelihood computed. The best map among all these maps is chosen as the new map unless this move is "taboo" (in CAR<sub>H</sub>AGENE a move is taboo is it has been used "recently" where the definition of recently varies stochastically during search). Actually, if the move is taboo and if the best map is better than the best known map, this best taboo map becomes the new map despite its taboo property. This process is repeated a number of times (precomputed by CAR<sub>H</sub>AGENE and equal to twice the number of markers) but extra iterations can be specified.

The whole process can be repeated a given number of times, starting each time from a different starting point. As the search proceeds, the user is informed of the status: if a new better solution is found, its loglikelihood is reported. If no better solution is found a "-" is printed. If the search detects it is stuck, always moving in the same region, a "\*" is printed and the search automatically restarted from a new starting point. If many such "\*" are printed, this is usually a good indication that the best solution has been found and is, repeatedly, found again and again.

The parameters of the search are given by the number of time the search process must be run, how many extra iterations are allowed and the bounds of variation for the definition of what a taboo move is. These bounds are defined as percentages and should therefore be between 1 and 99. Typical values are 5 and 30.

### 2.6.3 Genetic algorithm

The `algogen` command uses a genetic algorithm i.e., an optimizing algorithm based on the simulation of a reproduction/mutation/selection process. Maps are considered as individuals in a population of fixed size. They are bred together using a specific "mixing" process, some of them are mutated by flipping a random subsection and selected (maps which the highest loglikelihood have higher probabilities of participating in the next generation). The process is repeated over and over for a given number of generation

The command takes a number of parameters: number of generations, size of the population (a 0 here means the heap is used as the initial population), the selection type, the probability of breeding, of mutation and an extra parameter specifying that selection strength increases as generations go or not.

### 2.6.4 flips

Applies all possible permutations in a sliding window on the current best map and reports likelihood variations.

**Synopsis:** The `flips` command is invoked either as:

- `flips Options`
- `flips Size LOD-Threshold Iterative`

**Description:** The `flips` command applies all possible permutations in a sliding window of a given *Size* on the current best available map (the best map in the heap). If the map obtained has a loglikelihood within *LOD-Threshold* of the loglikelihood of the original map, then the permutation that lead to this map is displayed. If a new improved map is found, the `flips` command can be automatically iterated using a value of 1 for the last argument.

Note that this command can be also used to perform exhaustive search of all possible order when a small (< 10) number of markers is active by simply specifying the number of active markers as the sliding window size.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Size* : the *size* of the sliding window (cannot exceed 9),
- *LOD-Threshold*: the maximum difference of loglikelihood with the best map to report the permutation,
- *Iterative*: a boolean that indicates whether the `flips` command should be iterated as long as a new improved map has been found.

**Example :**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> group 0.1 7
```

```
Linkage Groups :  
-----:  
LOD threshold=7.00  
Distance threshold=10.00:
```

```
Group ID : Marker ID List ...  
1 : 17 19 20 18  
2 : 14  
3 : 11 13 12 16 15  
4 : 2 4 3 7 6 5 9 10 8  
5 : 1
```

```
5
```

```
CG> mrkselset [groupget 4]
```



```

# run this heuristic
CG> nicemapd

Map -1 : log10-likelihood =  -129.39
-----:
Set : Marker List ...
    1 : MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10

# the reliability of the result with a large flip
CG> flips 9 1 1

Repeated Flip(window size : 9, threshold : 1.00).

Map -1 : log10-likelihood =  -129.39
-----:
Set : Marker List ...
    1 : MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10

      1 log10
2 3 4 5 6 7 8 9 0  -129.39
[- - - - - 8 7]   -0.00
[7 8 6 5 - 3 2 1 0] -0.00
[8 7 6 5 - 3 2 1 0]  0.00

# the map was not optimal

```

#### See also:

- [polish \(2.6.5\)](#)
- [annealing \(2.6.7\)](#)
- [greedy \(2.6.8\)](#)

### 2.6.5 polish

Checks map reliability by swapping pairs of markers.

**Synopsis:** The `polish` command is invoked either as:

- `polish Options`
- `polish`

**Description:** For all the markers in the current best known map in the heap, the `polish` command displaces each marker in all possible intervals and reports the difference in log-likelihood in a matrix. Each line and column corresponds to a marker and displays the difference in loglikelihood of the maps obtained by displacing the marker of the line to the direct right of the marker in the column. A negative number indicates a better map has been found.

All the maps considered are candidates to be inserted in the heap and therefore any improvement obtained here is automatically memorized.

## Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.

**Returns:** nothing.

## Example:

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CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.

Type 'help' for help.

```
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> group 0.1 7
```

Linkage Groups :

-----;

LOD threshold=7.00

Distance threshold=10.00:

```
Group ID : Marker ID List ...
  1 : 17 19 20 18
  2 : 14
  3 : 11 13 12 16 15
  4 : 2 4 3 7 6 5 9 10 8
  5 : 1
```

5

```
CG> mrkselset [groupget 4]
```

```
CG> nicemapl
```

Map -1 : log10-likelihood = -148.06

-----;

Set : Marker List ...

```
  1 : MS2 MS3 MS4 MS7 MS8 MS9 MS6 MS5 MS10
```

```
CG> polish
```

Local map analysis:

	MS2	MS3	MS4	MS7	MS8	MS9	MS6	MS5	MS10
MS2	-----	1.2	22.3	43.7	58.2	38.4	35.9	29.9	27.9
MS3	1.2	-----	21.7	45.4	62.3	39.8	37.4	30.8	30.4
MS4	9.0	21.7	-----	23.1	38.1	19.5	14.2	10.5	12.5
MS7	21.0	44.3	23.1	-----	15.4	0.2	2.9	5.9	11.0
MS8	30.2	62.9	42.3	15.4	-----	0.1	16.2	11.0	12.2
MS9	26.6	57.9	40.1	15.9	0.1	-----	13.9	8.9	8.9
MS6	7.1	24.4	10.6	-4.3	-1.8	13.9	-----	2.7	1.5
MS5	7.8	24.6	2.8	-4.3	4.2	16.5	2.7	-----	1.4

```
MS10 | 4.3 19.9 4.5 3.1 -0.9 -1.7 -1.7 1.4 -----
-----
```

**See also:**

- `flips` (2.6.4)
- `annealing` (2.6.7)
- `greedy` (2.6.8)

## 2.6.6 `squeeze`

Expunge step by step non reliable loci from an initial map.

**Synopsis:** The `squeeze` command is invoked either as:

- `squeeze Options`
- `squeeze Threshold—ListOfThreshold Command`

**Description:** `squeeze` command provides a procedure to remove step by step non reliable loci from a map. The command starts from the best map stored inside the heap. Then it tests the removal of a single marker. Each marker is removed separately. If the shortest map is significantly shorter than the initial map according to a distance threshold in cMorgan (Haldane distance) for genetics data or cRay for Radiation Hybrids data, the marker is definitively removed. And the procedure is restarted. The default threshold is 50 cM/cR. In the case of multiple datasets merged with `dsmergor`, the distance is evaluated for each dataset separately and the marker is removed if at least one distance is greater than or equal to the corresponding distance threshold. At each restart, a command tries to disturb the current order of the markers kept so far. The default command that tries to disturb the order is: `{flips 3 0 2}`. To change this, you need to provide a second parameter. It has to be a regular carthogene command stored inside a list.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Threshold—ListOfThreshold* : a distance threshold in cMorgan (Haldane distance) for genetics data or cRay for Radiation Hybrids data. In the case of multiple loaded datasets merged with `dsmergor`, an ordered list of distance thresholds corresponding to the order of the datasets.
- *Command* : an optional command to be used to improve the current order after a marker removal.

**Returns:** nothing.

### Example:

CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.

Type 'help' for help.

```
# load two datasets and find markers which appear in linkage groups
# of size greater than 4 in the two datasets
CG> set mrkselection [multigroup 4 {0.5 0.5} {6 6} {Data/panelRH1.id Data/p...
```

Linkage Groups :

-----;

LOD threshold=6.00

Distance threshold=50.00:

Group ID : Marker ID List ...

1 : 151

2 : 125

3 : 93

4 : 15

5 : 4 36 60 73 79 104 118 123 138 150 161 160 159 158 157 156 155 1...

6 : 1 10 3 2

Linkage Groups :

-----;

LOD threshold=6.00

Distance threshold=50.00:

Group ID : Marker ID List ...

1 : 151

2 : 149

3 : 123

4 : 122 129 130 131 127 128 126 125 124 137 140 145 146 144 143 142...

5 : 121

6 : 119 120

7 : 118

8 : 116

9 : 115 117

10 : 110 114 113 112 111

11 : 102

12 : 93

13 : 80 81 85 92 100 106 103 105 104 101 99 97 96 95 94 91 98 90 89 ...

14 : 79

15 : 74 78 77 76 75

16 : 73

17 : 59 63 69 72 71 68 67 66 65 64 62 61 60 70

18 : 58

19 : 46 55 57 56 54 53 52 51 50 49 48 47

20 : 41 45 44 43 42

21 : 40

22 : 35 36 37 39 38

23 : 30 31

24 : 11 15 20 28 33 32 29 24 27 26 25 23 22 21 19 18 17 14 16 13 12 34

25 : 10

```

        26 : 4 9 8 7 6 5
        27 : 1 3 2
122 129 130 131 127 128 126 124 137 140 145 146 144 143 142 141 139 138 136...
CG>

```

```

# merge the two panels
CG> dsmergor 1 2
{3 merged by order 161 273}
CG>

```

```

# set the current selection of markers
CG> mrkselset $mrkselection

```

```
CG>
```

```

# remove double markers
CG> mrkdouble

```

Possible double markers:

```

        4 = 5                [45.9]

```

```

CG> mrkmerges
Markers 4 and 5 merged in 4.

```

```
CG>
```

```

# find a good map
CG> lkhn 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...

```

Map -1 : log10-likelihood = -2857.94

```

-----:
Set : Marker List ...
  1 : 105 98 87 89 90 97 99 101 100 104 103 108 114 111 112 113 110 109 10...
  2 : 105 98 87 89 90 97 99 101 100 104 103 108 114 111 112 113 110 109 10...

```

```
CG>
```

```

# remove dubious markers
CG> squeeze {50 60} {lkhn 1 -1}
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...

```

Those loci have been removed : 44 35 52 122 114 152  
The best map is now :

Map 0 : log10-likelihood = -2702.90

```

-----:
Set : Marker List ...
  1 : 105 98 87 89 90 97 99 101 100 104 103 108 111 112 113 110 109 107 10...
  2 : 105 98 87 89 90 97 99 101 100 104 103 108 111 112 113 110 109 107 10...

```

CG> bestprintd

Map 0 : log10-likelihood = -2702.90, log-e-likelihood = -6223.67  
-----;

Data Set Number 1 :

Pos	Id name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	105 105	35.3 cR	0.0 cR	29.8 %%	5.7
2	98 98	45.0 cR	35.3 cR	36.2 %%	4.8
3	87 87	18.1 cR	80.3 cR	16.5 %%	9.0
4	89 89	21.1 cR	98.4 cR	19.0 %%	9.6
5	90 90	60.5 cR	119.5 cR	45.4 %%	6.1
6	97 97	9.5 cR	180.0 cR	9.1 %%	17.4
7	99 99	3.1 cR	189.6 cR	3.1 %%	20.1
8	101 101	3.7 cR	192.7 cR	3.6 %%	18.9
9	100 100	20.1 cR	196.4 cR	18.2 %%	13.2
10	104 104	10.4 cR	216.5 cR	9.9 %%	14.0
11	103 103	18.0 cR	226.9 cR	16.4 %%	11.6
12	108 108	0.0 cR	244.9 cR	0.0 %%	21.7
13	111 111	6.7 cR	244.9 cR	6.5 %%	15.8
14	112 112	10.4 cR	251.6 cR	9.9 %%	14.0
15	113 113	3.3 cR	262.0 cR	3.2 %%	19.1
16	110 110	0.0 cR	265.3 cR	0.0 %%	21.7
17	109 109	3.3 cR	265.3 cR	3.2 %%	19.1
18	107 107	7.9 cR	268.5 cR	7.6 %%	15.1
19	106 106	50.4 cR	276.4 cR	39.6 %%	5.3
20	77 77	46.7 cR	326.8 cR	37.3 %%	5.5
21	74 74	17.1 cR	373.5 cR	15.7 %%	13.9
22	75 75	0.0 cR	390.7 cR	0.0 %%	22.1
23	76 76	6.2 cR	390.7 cR	6.0 %%	18.5
24	78 78	39.1 cR	396.9 cR	32.3 %%	8.9
25	80 80	34.2 cR	435.9 cR	29.0 %%	7.7
26	81 81	14.3 cR	470.2 cR	13.3 %%	12.4
27	82 82	3.2 cR	484.5 cR	3.2 %%	19.6
28	83 83	30.1 cR	487.7 cR	26.0 %%	9.4
29	84 84	20.4 cR	517.9 cR	18.5 %%	10.9
30	85 85	17.8 cR	538.3 cR	16.3 %%	12.9
31	86 86	10.7 cR	556.0 cR	10.1 %%	17.3
32	88 88	6.1 cR	566.7 cR	5.9 %%	19.4
33	91 91	3.7 cR	572.8 cR	3.6 %%	19.8
34	92 92	16.8 cR	576.5 cR	15.5 %%	14.1
35	96 96	0.0 cR	593.3 cR	0.0 %%	19.0
36	95 95	28.4 cR	593.4 cR	24.7 %%	9.6
37	94 94	115.7 cR	621.8 cR	68.6 %%	0.9
38	14 14	54.8 cR	737.5 cR	42.2 %%	2.1
39	39 39	33.3 cR	792.3 cR	28.3 %%	5.4
40	38 38	8.0 cR	825.6 cR	7.7 %%	13.8
41	37 37	11.2 cR	833.6 cR	10.6 %%	12.8
42	36 36	67.7 cR	844.8 cR	49.2 %%	4.6
43	9 9	19.4 cR	912.4 cR	17.6 %%	14.9
44	8 8	0.0 cR	931.8 cR	0.0 %%	18.6
45	7 7	25.0 cR	931.8 cR	22.1 %%	12.1
46	6 6	20.8 cR	956.7 cR	18.8 %%	10.0
47	5 5	0.0 cR	977.5 cR	0.0 %%	-----

47	4	4	20.2	cR	977.5	cR	18.3	%%	12.3
48	11	11	41.6	cR	997.7	cR	34.0	%%	6.7
49	12	12	15.8	cR	1039.3	cR	14.6	%%	10.6
50	13	13	11.1	cR	1055.1	cR	10.5	%%	12.8
51	17	17	3.6	cR	1066.2	cR	3.5	%%	15.9
52	16	16	0.0	cR	1069.8	cR	0.0	%%	19.3
53	18	18	3.6	cR	1069.8	cR	3.5	%%	15.9
54	19	19	7.2	cR	1073.3	cR	6.9	%%	14.6
55	21	21	8.9	cR	1080.5	cR	8.5	%%	14.6
56	20	20	11.9	cR	1089.4	cR	11.3	%%	12.4
57	24	24	14.1	cR	1101.3	cR	13.2	%%	10.7
58	27	27	9.6	cR	1115.5	cR	9.2	%%	12.4
59	23	23	9.6	cR	1125.1	cR	9.2	%%	13.2
60	22	22	15.3	cR	1134.7	cR	14.2	%%	12.0
61	26	26	7.3	cR	1150.0	cR	7.1	%%	14.7
62	25	25	24.7	cR	1157.4	cR	21.9	%%	9.1
63	28	28	7.5	cR	1182.1	cR	7.2	%%	14.4
64	29	29	0.0	cR	1189.6	cR	0.0	%%	17.0
65	32	32	3.6	cR	1189.6	cR	3.5	%%	16.7
66	33	33	3.6	cR	1193.1	cR	3.5	%%	16.7
67	34	34	47.6	cR	1196.7	cR	37.9	%%	5.0
68	57	57	9.6	cR	1244.3	cR	9.2	%%	10.6
69	56	56	49.1	cR	1253.9	cR	38.8	%%	6.0
70	60	60	13.6	cR	1303.0	cR	12.7	%%	12.0
71	64	64	33.1	cR	1316.6	cR	28.2	%%	6.6
72	67	67	39.6	cR	1349.6	cR	32.7	%%	6.3
73	68	68	3.6	cR	1389.3	cR	3.6	%%	19.9
74	70	70	16.7	cR	1392.9	cR	15.4	%%	15.5
75	72	72	6.6	cR	1409.6	cR	6.4	%%	15.4
76	71	71	10.9	cR	1416.2	cR	10.3	%%	14.2
77	69	69	23.6	cR	1427.1	cR	21.0	%%	11.5
78	66	66	11.8	cR	1450.7	cR	11.2	%%	13.1
79	65	65	21.3	cR	1462.5	cR	19.2	%%	10.5
80	63	63	20.3	cR	1483.8	cR	18.4	%%	12.1
81	62	62	6.0	cR	1504.2	cR	5.8	%%	19.4
82	61	61	26.6	cR	1510.2	cR	23.4	%%	11.7
83	59	59	9.8	cR	1536.8	cR	9.3	%%	16.3
84	55	55	10.2	cR	1546.5	cR	9.7	%%	15.3
85	49	49	14.3	cR	1556.7	cR	13.3	%%	13.3
86	51	51	0.0	cR	1571.0	cR	0.0	%%	18.2
87	54	54	6.7	cR	1571.0	cR	6.5	%%	17.1
88	53	53	0.0	cR	1577.7	cR	0.0	%%	21.0
89	48	48	0.0	cR	1577.7	cR	0.0	%%	21.7
90	50	50	0.0	cR	1577.7	cR	0.0	%%	21.7
91	47	47	8.6	cR	1577.7	cR	8.3	%%	15.7
92	46	46	23.3	cR	1586.4	cR	20.8	%%	12.0
93	41	41	26.8	cR	1609.7	cR	23.5	%%	10.1
94	42	42	7.0	cR	1636.5	cR	6.8	%%	15.9
95	43	43	3.4	cR	1643.5	cR	3.4	%%	17.9
96	45	45	163.4	cR	1646.9	cR	80.5	%%	0.5
97	136	136	19.1	cR	1810.3	cR	17.4	%%	7.3
98	131	131	22.3	cR	1829.4	cR	20.0	%%	8.2
99	133	133	78.5	cR	1851.6	cR	54.4	%%	3.6
100	147	147	17.0	cR	1930.1	cR	15.6	%%	13.5
101	150	150	25.0	cR	1947.1	cR	22.2	%%	12.3
102	157	157	10.7	cR	1972.2	cR	10.1	%%	17.6
103	156	156	26.4	cR	1982.9	cR	23.2	%%	11.6
104	154	154	9.8	cR	2009.3	cR	9.4	%%	15.7

105	159	159	14.3	cR	2019.1	cR	13.3	%%	16.9
106	161	161	0.0	cR	2033.4	cR	0.0	%%	26.5
107	160	160	11.2	cR	2033.4	cR	10.6	%%	18.4
108	158	158	8.4	cR	2044.6	cR	8.0	%%	19.1
109	155	155	11.2	cR	2053.0	cR	10.6	%%	18.4
110	153	153	5.7	cR	2064.2	cR	5.5	%%	20.6
111	148	148	5.8	cR	2069.9	cR	5.6	%%	19.7
112	146	146	17.9	cR	2075.6	cR	16.4	%%	15.2
113	143	143	8.7	cR	2093.5	cR	8.3	%%	19.2
114	145	145	3.4	cR	2102.2	cR	3.3	%%	20.7
115	144	144	50.0	cR	2105.6	cR	39.3	%%	7.4
116	138	138	19.3	cR	2155.5	cR	17.5	%%	12.9
117	141	141	8.7	cR	2174.8	cR	8.4	%%	16.9
118	142	142	10.0	cR	2183.5	cR	9.5	%%	13.9
119	139	139	10.0	cR	2193.5	cR	9.5	%%	13.9
120	140	140	3.1	cR	2203.5	cR	3.1	%%	20.1
121	132	132	3.1	cR	2206.6	cR	3.1	%%	20.1
122	137	137	0.0	cR	2209.8	cR	0.0	%%	22.7
123	135	135	9.9	cR	2209.8	cR	9.5	%%	16.4
124	134	134	39.4	cR	2219.7	cR	32.5	%%	6.6
125	129	129	18.5	cR	2259.1	cR	16.9	%%	8.9
126	128	128	22.5	cR	2277.6	cR	20.1	%%	7.3
127	130	130	46.2	cR	2300.0	cR	37.0	%%	4.5
128	127	127	18.7	cR	2346.2	cR	17.1	%%	8.9
129	126	126	25.7	cR	2364.9	cR	22.6	%%	9.6
130	124	124	-----						
			2390.6	cR					

130 markers, log10-likelihood = -866.11  
log-e-likelihood = -1994.29  
retention proba. = 0.20

Data Set Number 2 :

Pos	Id name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	105 105	65.9 cR	0.0 cR	48.3 %%	5.8
2	98 98	43.6 cR	65.9 cR	35.3 %%	7.9
3	87 87	29.2 cR	109.4 cR	25.3 %%	7.9
4	89 89	9.2 cR	138.7 cR	8.8 %%	12.7
5	90 90	42.7 cR	147.8 cR	34.7 %%	9.5
6	97 97	48.3 cR	190.5 cR	38.3 %%	10.9
7	99 99	17.0 cR	238.8 cR	15.7 %%	21.9
8	101 101	6.4 cR	255.8 cR	6.2 %%	29.6
9	100 100	15.4 cR	262.3 cR	14.3 %%	24.8
10	104 104	18.2 cR	277.6 cR	16.7 %%	22.6
11	103 103	68.0 cR	295.9 cR	49.3 %%	6.2
12	108 108	63.6 cR	363.9 cR	47.1 %%	5.4
13	111 111	12.3 cR	427.5 cR	11.6 %%	21.8
14	112 112	0.0 cR	439.8 cR	0.0 %%	34.4
15	113 113	13.2 cR	439.8 cR	12.3 %%	25.1
16	110 110	61.1 cR	452.9 cR	45.7 %%	10.6
17	109 109	22.1 cR	514.0 cR	19.8 %%	22.1
18	107 107	23.2 cR	536.1 cR	20.7 %%	18.4
19	106 106	157.2 cR	559.3 cR	79.2 %%	1.6
20	77 77	16.0 cR	716.5 cR	14.8 %%	18.6



21	74	74	29.9	cR	732.5	cR	25.9	%%	12.6
22	75	75	18.0	cR	762.4	cR	16.5	%%	16.2
23	76	76	14.2	cR	780.4	cR	13.3	%%	19.5
24	78	78	88.1	cR	794.7	cR	58.6	%%	5.2
25	80	80	36.7	cR	882.8	cR	30.7	%%	11.7
26	81	81	19.4	cR	919.5	cR	17.6	%%	16.9
27	82	82	19.3	cR	938.9	cR	17.5	%%	19.2
28	83	83	33.8	cR	958.2	cR	28.7	%%	14.5
29	84	84	26.2	cR	991.9	cR	23.1	%%	18.3
30	85	85	23.8	cR	1018.1	cR	21.2	%%	19.1
31	86	86	9.7	cR	1041.9	cR	9.2	%%	23.8
32	88	88	33.2	cR	1051.6	cR	28.3	%%	12.9
33	91	91	7.0	cR	1084.8	cR	6.8	%%	25.5
34	92	92	14.4	cR	1091.8	cR	13.4	%%	22.4
35	96	96	25.2	cR	1106.2	cR	22.3	%%	17.8
36	95	95	7.0	cR	1131.3	cR	6.7	%%	26.4
37	94	94	127.2	cR	1138.3	cR	72.0	%%	1.2
38	14	14	142.1	cR	1265.6	cR	75.9	%%	0.0
39	39	39	18.0	cR	1407.7	cR	16.5	%%	9.2
40	38	38	74.3	cR	1425.7	cR	52.4	%%	4.8
41	37	37	42.4	cR	1500.0	cR	34.5	%%	10.5
42	36	36	291.5	cR	1542.4	cR	94.6	%%	0.0
43	9	9	30.2	cR	1833.9	cR	26.0	%%	9.0
44	8	8	9.2	cR	1864.0	cR	8.8	%%	14.0
45	7	7	25.1	cR	1873.3	cR	22.2	%%	11.3
46	6	6	8.3	cR	1898.3	cR	8.0	%%	18.9
47	5	5	0.0	cR	1906.6	cR	0.0	%%	-----
47	4	4	82.7	cR	1906.6	cR	56.2	%%	2.7
48	11	11	11.6	cR	1989.3	cR	10.9	%%	16.1
49	12	12	12.1	cR	2000.9	cR	11.4	%%	17.0
50	13	13	29.1	cR	2013.0	cR	25.3	%%	12.4
51	17	17	12.0	cR	2042.1	cR	11.3	%%	20.5
52	16	16	8.5	cR	2054.1	cR	8.2	%%	23.3
53	18	18	15.8	cR	2062.6	cR	14.6	%%	18.7
54	19	19	10.2	cR	2078.4	cR	9.7	%%	21.4
55	21	21	4.9	cR	2088.7	cR	4.8	%%	25.3
56	20	20	39.9	cR	2093.6	cR	32.9	%%	8.5
57	24	24	15.7	cR	2133.5	cR	14.5	%%	12.4
58	27	27	11.9	cR	2149.2	cR	11.2	%%	15.1
59	23	23	0.0	cR	2161.0	cR	0.0	%%	22.3
60	22	22	9.6	cR	2161.0	cR	9.2	%%	18.1
61	26	26	4.5	cR	2170.7	cR	4.4	%%	20.4
62	25	25	13.7	cR	2175.2	cR	12.8	%%	17.9
63	28	28	41.2	cR	2188.8	cR	33.8	%%	7.6
64	29	29	18.2	cR	2230.0	cR	16.6	%%	11.3
65	32	32	33.5	cR	2248.2	cR	28.4	%%	9.8
66	33	33	14.4	cR	2281.7	cR	13.4	%%	17.0
67	34	34	111.7	cR	2296.1	cR	67.3	%%	3.5
68	57	57	2.4	cR	2407.8	cR	2.3	%%	30.6
69	56	56	64.6	cR	2410.2	cR	47.6	%%	9.1
70	60	60	27.5	cR	2474.8	cR	24.0	%%	14.0
71	64	64	34.4	cR	2502.3	cR	29.1	%%	10.1
72	67	67	13.7	cR	2536.7	cR	12.8	%%	17.9
73	68	68	37.6	cR	2550.4	cR	31.3	%%	7.6
74	70	70	47.5	cR	2587.9	cR	37.8	%%	5.4
75	72	72	41.3	cR	2635.4	cR	33.9	%%	10.3
76	71	71	9.5	cR	2676.8	cR	9.1	%%	24.5
77	69	69	30.4	cR	2686.3	cR	26.2	%%	16.4

78	66	66	16.8	cR	2716.7	cR	15.5	%%	21.5
79	65	65	17.4	cR	2733.5	cR	16.0	%%	20.1
80	63	63	14.1	cR	2750.9	cR	13.1	%%	23.2
81	62	62	2.3	cR	2765.0	cR	2.3	%%	31.4
82	61	61	39.1	cR	2767.3	cR	32.4	%%	15.1
83	59	59	100.3	cR	2806.4	cR	63.3	%%	5.1
84	55	55	33.6	cR	2906.8	cR	28.5	%%	16.7
85	49	49	14.2	cR	2940.4	cR	13.2	%%	22.8
86	51	51	20.4	cR	2954.5	cR	18.5	%%	18.5
87	54	54	12.9	cR	2975.0	cR	12.1	%%	19.5
88	53	53	19.0	cR	2987.8	cR	17.3	%%	15.3
89	48	48	11.7	cR	3006.8	cR	11.1	%%	20.5
90	50	50	8.5	cR	3018.5	cR	8.2	%%	22.4
91	47	47	12.4	cR	3027.1	cR	11.7	%%	21.1
92	46	46	58.8	cR	3039.4	cR	44.5	%%	7.5
93	41	41	5.5	cR	3098.2	cR	5.3	%%	21.0
94	42	42	2.7	cR	3103.7	cR	2.6	%%	23.3
95	43	43	5.5	cR	3106.4	cR	5.3	%%	21.0
96	45	45	93.2	cR	3111.9	cR	60.6	%%	2.5
97	136	136	85.2	cR	3205.0	cR	57.3	%%	3.4
98	131	131	14.0	cR	3290.2	cR	13.1	%%	16.9
99	133	133	190.3	cR	3304.2	cR	85.1	%%	0.6
100	147	147	86.9	cR	3494.5	cR	58.0	%%	7.1
101	150	150	33.0	cR	3581.4	cR	28.1	%%	17.4
102	157	157	24.7	cR	3614.4	cR	21.9	%%	19.5
103	156	156	22.7	cR	3639.1	cR	20.3	%%	20.4
104	154	154	31.9	cR	3661.8	cR	27.3	%%	17.6
105	159	159	23.5	cR	3693.7	cR	20.9	%%	22.5
106	161	161	23.5	cR	3717.2	cR	20.9	%%	22.5
107	160	160	14.6	cR	3740.7	cR	13.5	%%	25.1
108	158	158	12.1	cR	3755.2	cR	11.4	%%	26.1
109	155	155	17.0	cR	3767.3	cR	15.7	%%	25.1
110	153	153	45.4	cR	3784.4	cR	36.5	%%	12.9
111	148	148	31.4	cR	3829.7	cR	27.0	%%	17.4
112	146	146	44.6	cR	3861.2	cR	36.0	%%	15.1
113	143	143	25.3	cR	3905.7	cR	22.3	%%	22.1
114	145	145	6.9	cR	3931.0	cR	6.7	%%	30.8
115	144	144	62.8	cR	3937.9	cR	46.7	%%	9.6
116	138	138	20.4	cR	4000.7	cR	18.5	%%	15.3
117	141	141	38.4	cR	4021.1	cR	31.9	%%	10.4
118	142	142	18.9	cR	4059.5	cR	17.2	%%	20.0
119	139	139	4.6	cR	4078.3	cR	4.5	%%	29.8
120	140	140	19.5	cR	4082.9	cR	17.7	%%	23.6
121	132	132	21.7	cR	4102.4	cR	19.5	%%	22.7
122	137	137	16.9	cR	4124.1	cR	15.6	%%	22.8
123	135	135	19.6	cR	4141.0	cR	17.8	%%	18.5
124	134	134	68.5	cR	4160.6	cR	49.6	%%	6.0
125	129	129	10.4	cR	4229.1	cR	9.8	%%	21.8
126	128	128	8.5	cR	4239.5	cR	8.1	%%	23.8
127	130	130	16.9	cR	4247.9	cR	15.5	%%	20.7
128	127	127	2.6	cR	4264.8	cR	2.5	%%	33.4
129	126	126	7.8	cR	4267.4	cR	7.5	%%	31.1
130	124	124	-----						
			4275.2	cR					

130 markers, log10-likelihood = -1836.79  
log-e-likelihood = -4229.38

```
0                                retention proba. =      0.14
```

**See also:**

- `multigroup` (2.3.21)
- `polish` (2.6.5)

### 2.6.7 annealing

Tries to optimize the maximum multipoint loglikelihood using a dedicated simulated annealing stochastic optimization algorithm.

**Synopsis:** The `annealing` command is invoked either as:

- `annealing Options`
- `annealing LPlateau InitTemp FinalTemp Cooling`

**Description:** The `annealing` command tries to improve the loglikelihood of the best known order for the current list of active loci (the best map in the heap) using a dedicated simulated annealing search algorithm. The annealing simulation starts from the temperature *InitTemp* and repeats until the temperature *FinalTemp* has been reached using a geometric cooling schedule with a cooling parameter *Cooling* and constant temperature plateaus of length *LPlateau*. The initial temperature is automatically reajusted if it is too cold/hot.

During the search, the algorithm gives some feedback by printing the current temperature and a character “+” if an improved map has been found.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *LPlateau*: length of constant temperature plateaus in the colling schedule.
- *InitTemp FinalTemp*: starting/ending temperature for the simulated annealing.
- *Colling*: cooling schedule parameter. This parameter should be between 0 and 1 and is typically taken to be close to 1. The closest to 1 the longer but also the better the algorithm.

**Returns:** nothing. All the map explored by the algorithm are candidate for the heap.

### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.

Type 'help' for help.

# we first load a dataset
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
# perform linkage group detection (output omitted)
CG> group 0.3 3
...
# select group number 10
CG> mrkselset [groupget 10]

# put a (stupid) map in the heap
CG> sem

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

# use a (fast) annealing command
CG> annealing 100 100 0.1 0.9

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

Temp: 100.00 : +++
Temp: 90.00 :
Temp: 81.00 : +
Temp: 72.90 :
Temp: 65.61 :
Temp: 59.05 : +
Temp: 53.14 :
Temp: 47.83 :
Temp: 43.05 :
Temp: 38.74 :
Temp: 34.87 :
Temp: 31.38 :
Temp: 28.24 :
Temp: 25.42 :
Temp: 22.88 :
Temp: 20.59 :
Temp: 18.53 :
Temp: 16.68 :
Temp: 15.01 :
Temp: 13.51 :
Temp: 12.16 :
Temp: 10.94 :
Temp: 9.85 :
```

```

Temp: 8.86 :
Temp: 7.98 :
Temp: 7.18 :
Temp: 6.46 :
Temp: 5.81 :
Temp: 5.23 :
Temp: 4.71 :
Temp: 4.24 :
Temp: 3.82 :
Temp: 3.43 :
Temp: 3.09 :
Temp: 2.78 :  +
Temp: 2.50 :
Temp: 2.25 :
Temp: 2.03 :
Temp: 1.82 :
Temp: 1.64 :
Temp: 1.48 :
Temp: 1.33 :
Temp: 1.20 :
Temp: 1.08 :
Temp: 0.97 :
Temp: 0.87 :
Temp: 0.79 :
Temp: 0.71 :
Temp: 0.64 :
Temp: 0.57 :
Temp: 0.52 :
Temp: 0.46 :

# we check the map with a large flip
CG> flips 9 0 0

Single Flip(window size : 9, threshold : 0.00).

Map -1 : log10-likelihood =  -141.81
-----;
Set : Marker List ...
    1 : G7 G12 G13 G16 G6 G5 G17 G18 G14

    2 2 2 3 2 1 3 3 2  log10
    1 6 7 0 0 9 1 2 8   -141.81
[8 7 6 5 - 3 2 1 0]      0.00

# the map found was indeed optimal

```

**See also:**

- greedy (2.6.8)
- flips (2.6.4)
- polish (2.6.5)

### 2.6.8 greedy

Tries to optimize the maximum multipoint loglikelihood using a dedicated taboo search algorithm.

**Synopsis:** The `greedy` command is invoked either as:

- `greedy Options`
- `greedy NbLoop Fuel TabooMin TabooMax Anytime`

**Description:** The `greedy` command tries to improve the loglikelihood of the best known order for the current list of active loci (the best map in the heap) using a dedicated taboo search algorithm. This iterative algorithm will automatically compute a minimum number of iterations but additional iterations can be requested by setting the parameter *Fuel* to perform additional iterations. The *TabooMin TabooMax* indicates the minimum and maximum length of the taboo list which varies stochastically during search. These two parameters are %ages (between 0 and 100). Finally, the search is repeated *NbLoop* times if requested. The *Anytime* ratio controls the tradeoff between search speed and solution quality. It may vary from 0 to 100.

During the search, the algorithm gives some feedback by printing either:

- the “-” character: iterations have been performed without improving the best known map.
- the “\*” character: the algorithm has detected it is exploring orders it has already considered before on several occasions and decides to start a new search from a new order.
- “[number]”: a new improved map has been found.

#### Arguments :

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *NbLoop*: the number of times the taboo search is repeated.
- *Fuel*: the extra number of iterations requested. By default, an heuristically determined number of iterations is computed. If the Fuel is positive, an extra number of iterations are performed. If the Fuel is negative then the number of iterations performed will be *exactly* equal to the absolute value of the Fuel. For instance, the following command tests all submap reversals: `greedy 1 -1 5 30 0`.
- *TabooMin TabooMax*: the minimum and maximum size of the taboo list in %age (between 0 and 100).
- *Anytime*: the %age (between 0 and 100) of the neighborhood explored at each move. A value 100% means all the possible swaps (i.e. reversing the order of a consecutive sublist of markers) are examined. A smaller strictly positive value will speed up the search, improving solution quality faster at the beginning of the search. But solution quality may be altered at the end. A typical value may be 25%. A value of 0 corresponds to the original Carthage release 0.5 taboo search algorithm.

**Returns:** nothing. All the map explored by the algorithm are candidate for the heap.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> group 0.3 3
...
CG> mrkselset [groupget 10]

CG> sem

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

CG> greedy 1 0 5 25 0

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
1 : G5 G18 G17 G14 G16 G13 G12 G6 G7
Run number 0

[-153.81]
[-148.65]
[-145.59]
[-145.08]-
[-143.70]
[-141.81]-----*****-----*-

CG> flips 9 0 0

Single Flip(window size : 9, threshold : 0.00).

Map -1 : log10-likelihood = -141.81
-----:
Set : Marker List ...
1 : G7 G12 G13 G16 G6 G5 G17 G18 G14

2 2 2 3 2 1 3 3 2 log10
1 6 7 0 0 9 1 2 8 -141.81
```

**See also:**

- annealing(2.6.7)

- `algogen` (2.6.9)
- `flips` (2.6.4)
- `polish` (2.6.5)

### 2.6.9 `algogen`

Tries to optimize the maximum multipoint loglikelihood using a dedicated genetic algorithm.

**Synopsis :** The CarthaGene `algogen` command is invoked as either one of :

- `lelacommande Options`
- `lelacommande NbGen NbMap SelType ProbaCross ProbaMut EvolFitn`

**Description :** The genetic algorithm tries to optimize the loglikelihood of orders using a simulation of mating, mutation and selection by fitness. The initial population is defined by the best maps stored in the heap or from generated maps.

As the algorithm runs, “+” are printed on a generation such that a map is found that improves over the best map known.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- The *Nbgen* argument correspond to the number of generations simulated.
- The *NbMap* argument correspond to the size of the population. If *NbMap* is set to 0, the command uses the heap to initialize the first generation population.
- The *SelType* argument specifies the type of selection used (0 for the roulette wheel, 1 for the stochastic remainder without replacement).
- The *ProbaCross* argument correspond to the probability of crossing-over. A typical value is 60 %.
- The *ProbaMut* argument correspond to the probability of mutation. A typical value is 5 to 10 %.
- The *EvolFitn* is a flag to set the evolutive fitness (0 or 1) which mean that selection becomes harder and harder with generations.

**Returns :** nothing, all maps explored are candidate for being stored in the heap.

**Example :**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```



```

# we load a dataset
CG> dsload Data/rh.cg
{1 haploid RH 53 118 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
# perform linkage group detection (output omitted)
CG> group 0.3 3
...
# we select the group 10
CG> mrkselset [groupget 10]

# put one (stupid) map in the heap using the 'sem' command
CG> sem

Map -1 : log10-likelihood = -161.87
-----:
Set : Marker List ...
1 : G5 G18 G17 G14 G16 G13 G12 G6 G7

# launch the 'algogen' command
CG> algogen 10 8 1 0.6 0.1 1
+
-
-
-
-
-
-
-
-
-

# check the reliability of the result with a large flip
CG> flips 9 0 0

Single Flip(window size : 9, threshold : 0.00).

Map -1 : log10-likelihood = -141.81
-----:
Set : Marker List ...
1 : G7 G12 G13 G16 G6 G5 G17 G18 G14

2 2 2 3 2 1 3 3 2 log10
1 6 7 0 0 9 1 2 8 -141.81
[8 7 6 5 - 3 2 1 0] 0.00

# the map was optimal

```

#### See also:

- greedy (2.6.8)
- annealing (2.6.7)
- flips (2.6.4)

- `polish` (2.6.5)

## 2.6.10 `mcmc`

Provide a map distribution using Markov Chain Monte Carlo. It works only in the comparative mapping approach (Section 2.7), for that a reference order dataset has to be loaded and merged with the biological dataset.

**Synopsis:** The `mcmc` command is invoked either as:

- `mcmc Options`
- `mcmc RandomSeed NbIter Burning`

**Description:** The `mcmc` command is Markov Chain Monte Carlo algorithm for estimating the posterior distribution of the marker order. It starts from the best map found in the CarthaGene heap. In order to visit maps, it uses a stochastic-biased complex (2-opt submap reversals, single marker re-insertions, and submap transpositions) operator based on 2-point likelihood genetic / Radiated Hybrid data. The random generator number is initialized with the *RandomSeed* parameter (should be a strictly positive integer). The number of iterations of MCMC is controlled by the *NbIter* parameter. At the end, it gives a list of maps with their posterior probability. The first *Burning* iterations are not used to estimate the map distribution. The maps are inserted in the CarthaGene heap. The map distribution is written to a file names `PID.mcmc` where `PID` is the Process ID of the current carthagene session.

The format of the output file is as follows: the first line recalls the starting map, then each line is a map from the distribution, sorted in decreasing (multipoint) posterior probability. For each line, it is indicated (in that order): the posterior probability using the multipoint likelihood, the posterior probability using the 2-pt approximation of the likelihood, the weight measuring the ratio of these two probabilities, the number of breakpoints with the reference order and finally the map given as the positions of the markers relative to the starting map (from 0 to N-1) where N is the number of markers.

### Arguments :

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *RandomSeed*: the random generator seed.
- *NbIter*: the number of iterations requested.
- *Burning*: the number of iterations (less than *NbIter*) for the burning period (these iterations are not taken into account in the final map distribution).

**Returns:** An output file containing the map distribution.

### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh12_true.cg
{1 haploid RH 51 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user/...
CG> dsload Data/order12_ref.cg
{2 order 51 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple/...
CG> dsmergor 1 2
{3 merged by order 51 93}
CG>
```

```
#select the comparative mapping criterion
CG> dsbplambda 2 1 1
New coefficient factor value is -2.682486.
1.0
CG>
```

```
#find a first good map
CG> lkhn 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...
```

```
Map -1 : log10-likelihood = -565.26
-----:
Set : Marker List ...
  1 : UniSTS208857 UniSTS180455 UniSTS160247 UniSTS160246 UniSTS180454 Uni...
  2 : UniSTS208857 UniSTS180455 UniSTS160247 UniSTS160246 UniSTS180454 Uni...
```

CG>

```
#compute map distribution starting from this initial map
#see result in ProcessID.mcmc output file
CG> mcmc 1 1000 500
[-5.3e+02]
key#: 0 2pt_loglike: -527.82
Maximum transposed segment size = 10
[-492.47]
[-489.98]
[-489.54]
[-487.35]
[-486.90]
Completed. 179 maps visited. time elapsed:5.75 sec.
MCMC done
Gibbs: accepted/proposed = 0.002929
Computing IS weights:
```

Done.

totaltime= 5.94 sec.

CG>

### See also:

- dsbplambda (2.7.2)
- buildfw (2.5.18)

- `cgrobustness` (2.5.19)

### 2.6.11 Interrupting

The `ctrl-c` sequence will enable the user to register a request of interruption of the current command. The demand will be treated next time a map is computed. The heap of already computed maps remains consistent.

This functionality allow to abort a command taking too much time. The best maps met so far will be kept into the heap and also you can keep on running commands.

## 2.7 Comparative mapping

When a subset of the markers are associated to genes having a known orthologous relationship with the genes of a completely sequenced genome, then it is possible to take advantage of the order of the orthologous genes in the sequenced genome (*reference order*) for the purpose of mapping a genome of interest. The rationale for this is that closely related organisms differ by a small number of chromosomal rearrangements, in comparison to the number of genes they have in common, and have therefore long conserved chromosomal segments. The comparative mapping approach in `CARTAGENE` extends its traditional maximum multipoint likelihood criterion by incorporating a non-uniform prior distribution on the possible orders. The a priori probability of an order is a function of its evolutionary distance to a given reference order. The number of *breakpoints* between an order and the reference order is used as a measure of the evolutionary distance. This number of breakpoints is the number of adjacent markers in an order which are not adjacent in the reference order.

`CARTAGENE` proposes two approaches for maximizing this new comparative mapping criterion. The first approach replaces the traditional criterion by the comparative mapping criterion, and then the usual `CARTAGENE` commands can be used to build a first map and to improve it. The second approach finds a set of maps, and then chooses the best map inside this set. See the paragraph below for an explanation. The first approach should be used if the number of selected markers is small enough (lower than one hundred) or if the number of known orthologous relationships is close to the number of selected markers and the number of missing data is limited (in this case the linear approximation of the comparative mapping criterion to the Traveling Salesperson Problem works well). Otherwise, the second approach is recommended. Both approaches are independent.

In Figure 2.1 Left, all the possible marker orderings are represented by several concentric circles, each circle corresponding to the set of orders having a fixed number of breakpoints to the reference order. Intuitively, the a priori probability of finding the true order having a particular number of breakpoints is reversely proportional to the number of possible orders at this number of breakpoints. For a fixed number of breakpoints, the optimal order is the one which has the maximum multipoint likelihood taken into account the biological dataset only. In order to find the best order given a biological dataset *and* a reference order, the comparative mapping approach first search for all the optimal orders at every number of breakpoints. These orders are represented in the figure by a set of points on a straight line segment delimited by the reference order (zero breakpoint) and the order which maximizes the traditional mapping criterion (here, five breakpoints). This set of optimal orders defines the so-called *Pareto frontier*<sup>4</sup>. The order which maximizes the criterion of the comparative mapping approach is chosen among the Pareto frontier. In Figure 2.1 Right, the two criteria for the different orders in the Pareto frontier are shown. In this example, taken from mouse chromosome 1 using the human genome as a reference order, the best map has 7 breakpoints compared to the 41 breakpoints found by the traditional approach based on a biological dataset only. For this example, the true map has 6 breakpoints.

<sup>4</sup>This term comes from the field of *Multiobjective Combinatorial Optimization*.

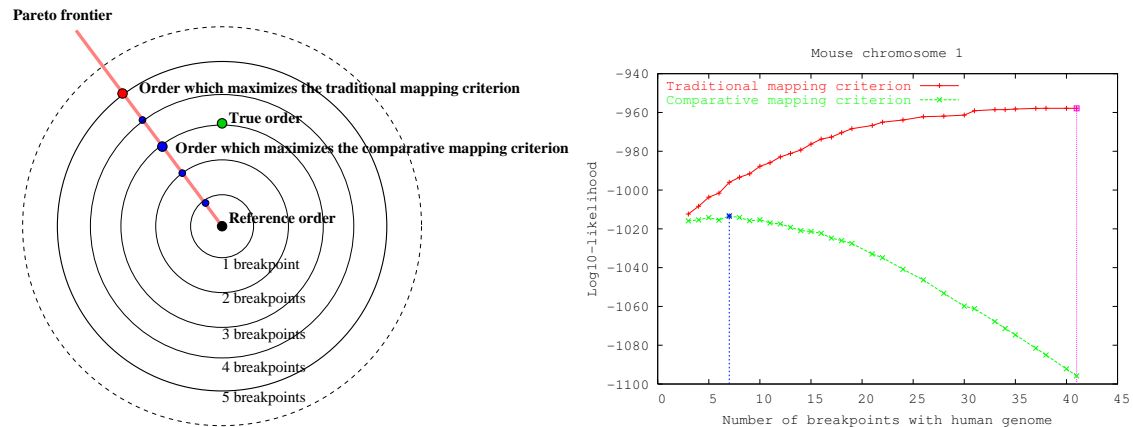


Figure 2.1: The comparative mapping criterion taking into account a biological dataset and the number of breakpoints to a reference order versus the traditional mapping criterion taking into account a biological dataset only.

### 2.7.1 Replacing the traditional criterion by the comparative mapping criterion

The first step is to combine a biological dataset and a reference order dataset using the merging operator `dsmergor`. The second step is to replace the traditional maximum multipoint likelihood criterion by the comparative mapping criterion. This is done by the `dsbplambda` command using its coefficient factor `auto fit` option.

### 2.7.2 `dsbplambda`

Replaces the traditional criterion by the comparative mapping criterion for a given order data set.

**Synopsis:** The `dsbplambda` command is invoked as:

- `dsbplambda SetID CoefAutoFit NewLambdaValue`

**Description:** The `dsbplambda` command sets the `lambda` parameter value used in the definition of the comparative mapping criterion. The parameter `SetId` corresponds to the reference order dataset numerical id. Set the `CoefAutoFit` parameter to 1 in order to replace the traditional criterion by the comparative mapping criterion. Then, all the Carthagene map printing, building or improving commands will use this new criterion. By default, set the `NewLambdaValue` parameter to 1.

#### Arguments:

- `SetId`: the numerical id of the reference order dataset.
- `CoefAutoFit`: must be set to 1.
- `NewLambdaValue`: it corresponds to the expected number of breakpoints between the true order and the reference order given by dataset `SetId`. In general, this number of breakpoints is unknown, and it should be set to 1, or preferably to the minimum number of obligate breakpoints (the number of segments minus one in the reference order dataset) if greater than one.

**Returns:** the previous `lambda` parameter value (default value is one).

### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rhl_true.cg
{1 haploid RH 110 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsload Data/order1_ref.cg
{2 order 110 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple...
CG> dsmergor 1 2
{3 merged by order 110 93}
#select the comparative mapping criterion
CG> dsbplambda 2 1 1
New coefficient factor value is -3.356208.
1.0
#find a first good map
CG> lkh 1 -1
This version of CarthaGene has been compiled without Keld Helsgaun's LKH TS...

Map -1 : log10-likelihood = -1176.46
-----:
Set : Marker List ...
  1 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...
  2 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...

#try to improve this map (could be very slow depending on the last paramete...
CG> greedy 1 0 5 10 5

Map -1 : log10-likelihood = -1176.46
-----:
Set : Marker List ...
  1 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...
  2 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...
Run number 0

[-1176.06]
[-1175.11]
[-1173.83]
[-1172.61]
[-1169.35]
[-1167.44]
[-1163.84]-
[-1157.25]-
[-1156.21]--
[-1155.28]
[-1155.23]
[-1148.11]-----
[-1142.97]
[-1141.36]-
[-1141.31]
[-1139.44]
[-1135.86]-----
[-1135.49]
```

```

[-1135.07]
[-1129.32]-----...

#show the best map in the heap
CG> bestprint

Map 10 : log10-likelihood = -1129.32
-----:
Set : Marker List ...
  1 : UniSTS158779 UniSTS164109 UniSTS158781 UniSTS158776 UniSTS207126 Uni...
  2 : UniSTS158779 UniSTS164109 UniSTS158781 UniSTS158776 UniSTS207126 Uni...
10
CG>

```

**See also:** The description of how to build a reference order dataset in the 'Formatting the data' section.

### 2.7.3 Building a Pareto frontier from scratch

The first step is to combine a biological dataset and a reference order dataset using the merging operator `dsmergor`. The second step is to build an initial Pareto frontier using the `paretolkh` or `paretolkhcn` command. The resulting frontier is stored into the `CARHAGENE` heap the size of which has been resized to the number of selected markers<sup>5</sup>. The previous content of the heap has no effect in the mapping process and was first discarded. The process of building a Pareto frontier is based on an efficient transformation from the comparative mapping criterion to a bi-objective Traveling Salesman Problem. The resulting frontier is only an approximation of the exact frontier. The quality of this approximation depends on the number of missing data and the number of orthologous markers<sup>6</sup>. The best configuration corresponds to the case of no missing data and all markers belonging to the reference order dataset. Even in this case, the resulting frontier is still an approximation due to the bi-objective solving technique used in `CARHAGENE`. Thus, it is still possible to improve the frontier, see Section 2.7.7.

For efficiency reasons, `CARHAGENE` is using the Keld Helsgaun's LKH software (non GPL code). Currently, the implemented `lkh` command works only with backcross, haploid RH, or a combination of both data types (`dsmergor`)<sup>7</sup>.

It is possible to speed up the `paretolkh` or `paretolkhcn` commands by changing the way `CARHAGENE` evaluates a map before it is inserted into the heap. See the `cg2pt` command. Moreover, the `paretolkh` or `paretolkhcn` commands are using a temporal heap during their process the size of which is arbitrarily fixed to 1024 (all the maps found at each step of the process are stored into this temporal heap before being evaluated in order to update the Pareto frontier). This size can be increased if the number of orthologous markers is large (see the `paretoheapsize` command).

### 2.7.4 `paretolkh`

Provide a Pareto frontier approximation.

**Synopsis:** The `paretolkh` command is invoked as either one of :

- `paretolkh Options`
- `paretolkh Resolution NbRun CollectMaps`

<sup>5</sup>The maximum number of maps in the Pareto frontier is equal to the number of selected markers minus one.

<sup>6</sup>a marker with no known orthology information is approximated by temporally adding the marker in the reference order such that the marker is the singleton element of a dummy chromosome.

<sup>7</sup>The 2-point loglikelihood contribution between two adjacent markers occurring in two different datasets is equal to zero.

**Description:** The `paretolkh` command creates a Pareto frontier from scratch. The result is a collection of maps, inserted into the heap, each map having a different number of breakpoints with a reference order. The current data set should be a merged by order between a biological data set and a reference order data set. `paretolkh` applies the weighted sum method for combining the 2-point loglikelihood (MLE) criterion from the biological data with the number of breakpoints (BP) criterion, approximated in the case of missing orthologous relationships. The weighted objective coefficient applied to the number of breakpoints is the product of a normalization factor and a weighted factor. The normalization factor  $r$  is obtained by finding first the initial ranges of the two criteria ( $r = \frac{\max(MLE) - \min(MLE)}{\max(BP) - \min(BP)}$ ). The weighted factor is equal to  $\frac{i}{Resolution - i}$  with  $i$ , a positive integer varying between 1 and  $Resolution - 1$ . The *Resolution* parameter controls the number of iterations of the weighted sum method. Each iteration corresponds to a mono-objective Traveling Salesman Problem with a different coefficient value ( $\frac{r \times i}{Resolution - i}$ ) solved by Keld Helsgaun's LKH software. Each iteration uses as a first starting point the best map found by the previous iteration. In order to improve the Pareto frontier, CAR<sub>H</sub>AGENE first generates an initial map by optimizing only one single objective (2-point loglikelihood criterion first), and then to start from this map a sequence of LKH iterations by varying  $i$  from 1 to  $Resolution - 1$ . This search strategy is applied twice. The second time, it starts from the best map found with the minimum number of breakpoints and vary  $i$  from  $Resolution - 1$  to 1. The final map found by each iteration is called *supported* and is locally optimal w.r.t. the LKH neighborhood. Some maps in the Pareto frontier are called *dominated* if there exists another map in the frontier which has less breakpoints and a better likelihood. The best map in the frontier is called *balanced*. The *NbRun* and *CollectMaps* parameters control the LKH method. See `lkh` 2.5.8. In order to get non supported maps and a better Pareto frontier approximation, use *CollectMaps* greater than or equal to 0. Each map found by the weighted sum method is assessed by computing the exact multipoint likelihood<sup>8</sup> and the exact number of breakpoints. Note that the loglikelihoods written during the iterative process have no meaning (internal use only).

Try `paretolkh 10 1 0` as default parameter values.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Resolution* : Controls the number of iterations of the weighted sum method. See above. This number should be related to the number of markers.
- *NbRun* : Repeats *NbRun* times the LK heuristic. At each run, LKH tries different starting points (the number of starting points is equal to the number of markers ; if the heap was not empty, the best map in the heap is used as the first starting point, other starting points are randomly generated).
- *CollectMaps* : Possible values are -1, 0, 2, 3, 4 and 5. If *CollectMaps* is  $\geq 0$  then every tour found by LKH is inserted into the CarthaGene heap. Moreover, a positive value sets the backtrack move type of LKH. If set to -1, only locally optimal tours w.r.t. the LK neighborhood are inserted into the heap.

**Returns:** nothing.

#### See also:

- `paretolkh` (2.7.5)
- `lkh` (2.5.8)
- `cg2pt` (2.8.10)

---

<sup>8</sup>Except in the case of the fast EM mode set by the `cg2pt` command.



### 2.7.5 `paretolkh`

Provide a Pareto frontier approximation.

**Synopsis:** The `paretolkh` command is invoked as either one of :

- `paretolkh Options`
- `paretolkh Resolution NbRun CollectMaps`

**Description:** The `paretolkh` command creates a Pareto frontier from scratch. The method is identical to the one used in `paretolkh`, except that it uses the *normalized* 2-point loglikelihood criterion for the biological data.

**Returns:** nothing.

**See also:**

- `paretolkh` (2.7.4)

### 2.7.6 `paretoheapsize`

Set the size of the (internal) heap used by `paretolkh` and `paretogreedy` commands.

**Synopsis :** The CarthaGene `paretoheapsize` command is invoked as either one of :

- `paretoheapsize Options`
- `paretoheapsize NbMap`

**Description :** `paretoheapsize` sets the size of the map container used by `paretolkh` and `paretogreedy` commands. `paretogreedy` will resize the current heap using this value. `paretolkh` uses an internal heap the size of which will be set to this value (at the end of `paretolkh` function, the current heap size is set to the current number of selected markers). The default value is 1024.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *NbMap* : The number of maps the heap must contain. The *NbMap* argument must be a positive non null integer.

**See also :**

- `heapsize` (2.4.2)
- `paretolkh` (2.7.4)
- `paretogreedy` (2.7.8)

### 2.7.7 Improving an existing Pareto frontier

An existing Pareto frontier can be improved by using the `paretogreedy` or `paretogreedyr` commands. The idea is to apply a perturbation on each map in the frontier. If a new map is found which has a better maximum multipoint likelihood compared to an existing map in the frontier with the same number of breakpoints, then this new map replaces the existing map in the frontier. As in the `greedy` command, the perturbation mechanism is to flip a subsection of the map. This process can be very long because all the possible flips are tried for each (new) map in the frontier. The process ends when no map in the frontier can be improved. It is possible to speed up this process by exploring only a subset (the most promising one) of the set of possible flips (see the `Anytime` parameter). Moreover, the `paretogreedyr` command allows to focus on a particular portion of the frontier only, in order to improve the frontier locally around the best map previously found by `paretolkh`.

At the end of a `paretogreedy` or `paretogreedyr` command, the heap contains all the maps in the Pareto frontier, but also the maps found during the search. The heap size depends on the last call to the `paretoheapsize` command (and by default, it is equal to 1024).

### 2.7.8 `paretogreedy`

Improve a Pareto frontier approximation.

**Synopsis:** The `paretogreedy` command is invoked either as:

- `paretogreedy Options`
- `paretogreedy Anytime`

**Description:** The `paretogreedy` command tries to improve an existing Pareto frontier approximation. It uses the bi-objective multipoint likelihood criterion and the number of breakpoints criterion to assess and improve maps in the frontier. The command starts from all the maps stored into the heap. The 2-change neighborhood (reversing any subsection of the map) is visited for each map. Each time a non dominated map is found, it is stored into the heap, updating the frontier. The algorithm stops when all the maps have been visited. The *Anytime* ratio controls the tradeoff between search speed and solution quality. The total neighborhood size is equal to  $\frac{NbMarkers(NbMarkers-1)}{2}$ . It is partially explored, depending on the *Anytime* ratio, but at least  $2 * NbMarkers$  neighbors are explored for each map in the frontier.

**Arguments :**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Anytime*: the *%age* (between 1 and 100) of the neighborhood explored. A value 100% means all the possible flips (i.e. reversing the order of a consecutive sublist of markers) are examined. A smaller strictly positive value will speed up the search, improving solution quality faster at the beginning of the search. But solution quality may be altered at the end. A typical value is 25%.

**Returns:** nothing. All the map explored by the algorithm are candidate for the heap.

**See also:**

- `paretogreedyr` (2.7.9)
- `paretolkh` (2.7.4)
- `greedy` (2.6.8)

## 2.7.9 `paretogleedyr`

Improve a selection of the Pareto frontier approximation.

**Synopsis:** The `paretogleedyr` command is invoked either as:

- `paretogleedyr Options`
- `paretogleedyr Anytime MinBP MaxBP`

**Description:** The `paretogleedyr` command is identical to the `paretogleedy` command, except that it focuses its perturbation strategy on the maps in the frontier having a number of breakpoints in the interval  $[MinBP, MaxBP]$ .

**New arguments :**

- *MinBP*: Only maps having a number of breakpoints greater than or equal to *MinBP* are considered for the exploration of their neighborhood.
- *MaxBP*: Only maps having a number of breakpoints lower than or equal to *MaxBP* are considered for the exploration of their neighborhood.

**Returns:** nothing. All the map explored by the algorithm are candidate for the heap.

**See also:**

- `paretogleedy` (2.7.8)

## 2.7.10 Finding the best map in an existing Pareto frontier

The best map in an existing Pareto frontier is obtained by the `paretobestprint` (order is given) and `paretobestprintd` (order and distances are given) commands. These commands have a special *lambda* parameter which corresponds to the expected number of breakpoints between the true order and the reference order. In general, this number is unknown (we don't know the true order!), and should be set to its minimum value (1 or the minimum number of obligate breakpoints if greater than one<sup>9</sup>). However, if the evolutionary distance can be assessed by some external (phylogeny) methods, then the knowledge of the number of breakpoints deduced from this evolutionary distance can slightly improve the quality of the best map found by `paretobestprint` and `paretobestprintd`.

The command `paretoplotg` gives a graphical view of the Pareto frontier (that can be zoomed, printed or saved). It draws the traditional and comparative mapping criteria for the maps in the frontier. An example is given in Figure 2.2 (the red triangle corresponds to the best map). By clicking on any point in the frontier, a comparative mapping view can be obtained between the corresponding map and the reference order. An example is given in Figure 2.2 (the distance between adjacent markers can be fixed or proportional).

The command `paretosave` allows to save the current Pareto frontier, for future use.

## 2.7.11 `paretobestprint`

Concisely describes the best map in the current Pareto frontier.

---

<sup>9</sup>An obligate breakpoint occurs between two adjacent markers from two different chromosomes in the reference genome.

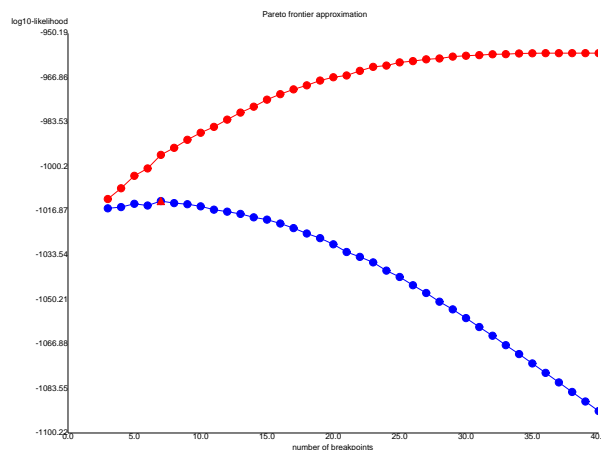


Figure 2.2: Graphical view of a Pareto frontier.

**Synopsis:** The `paretobestprint` command is invoked as:

- `paretobestprint Lambda`

**Description:** The `paretobestprint` command prints a concise description of the best map in the current Pareto frontier. The current Pareto frontier is first extracted from the existing maps in the heap (for each different number of breakpoints, the map which has the maximum likelihood w.r.t. the biological data is selected). Then, the best map is chosen which maximizes the extended likelihood criterion. The traditional  $\log_{10}$ -likelihood of the map is printed followed by the order of all the markers (by name), and for each dataset.

**Arguments:**

- *Lambda* : it corresponds to the expected number of breakpoints between the true order and the reference order. if unknown, it should be set to 1 or to the minimum number of obligate breakpoints (the number of segments minus one in the order dataset) if greater than one.

**Returns:** the identifier of the best map in the frontier.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.
```

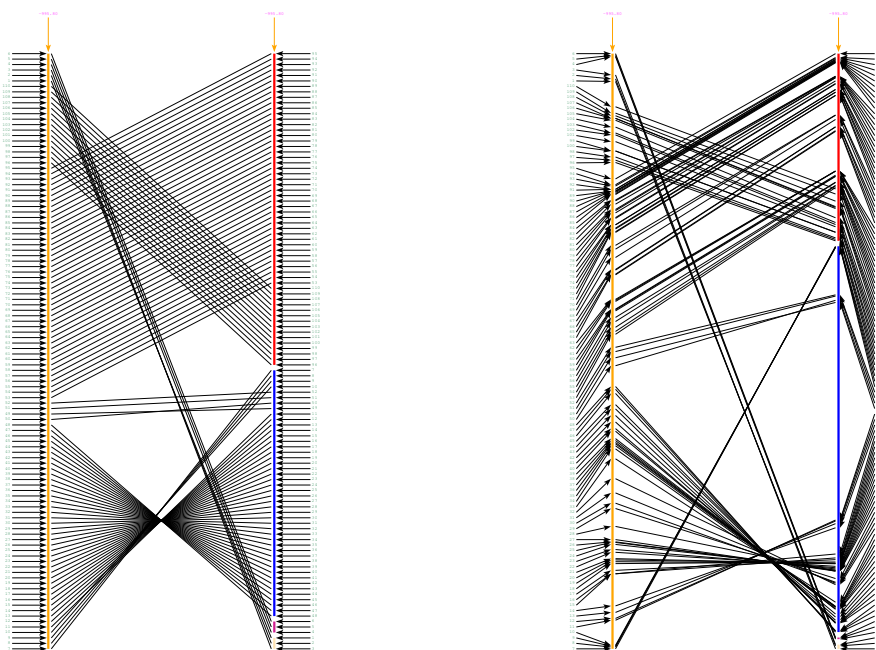


Figure 2.3: Comparative mapping views between the best order (left strand) and the reference order (right strand). Distances between adjacent markers are fixed (left figure) or proportional (right figure).

Type 'help' for help.

```
CG> dsload Data/rhl_true.cg
{1 haploid RH 110 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsload Data/order1_ref.cg
{2 order 110 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple...
CG> dsmergor 1 2
{3 merged by order 110 93}
#build a Pareto frontier from scratch
CG> paretolkh 10 1 0
...
#show the best map in the frontier
CG> paretobestprint 1

Pareto frontier approximation (coverage: 3 / 5 = 60.00 %):
Ranges: Log10-likelihood [-1015.005,-1000.007] / BP [49,53] = 3.7495
Id:   2 BP:  53 Log10-like: -1000.007 Log10-like+bp: -1180.530
Id:   1 BP:  51 Log10-like: -1002.978 Log10-like+bp: -1176.461      **...
Id:   0 BP:  49 Log10-like: -1015.005 Log10-like+bp: -1181.422

Map  1 : log10-likelihood = -1002.98
-----:
Set  : Marker List ...
      1 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...
      2 : UniSTS178358 UniSTS207126 UniSTS158776 UniSTS164109 UniSTS158779 Uni...
1
CG>
```

#### See also:

- `paretobestprintd` (2.7.12)
- `paretoplotg` (2.7.13)

### 2.7.12 `paretobestprintd`

Precisely describes the best map in the current Pareto frontier.

**Synopsis:** The `paretobestprintd` command is invoked as:

- `paretobestprintd Lambda`

**Description:** The `paretobestprintd` command prints an extensive description of the best map in the current Pareto frontier. The current Pareto frontier is first extracted from the existing maps in the heap (for each different number of breakpoints, the map which has the maximum likelihood w.r.t. the biological data is selected). Then, the best map is chosen which maximizes the extended likelihood criterion. See the command `bestprintd` for a description of the output.

#### Arguments:

- *Lambda* : it corresponds to the expected number of breakpoints between the true order and the reference order. if unknown, it should be set to 1 or to the minimum number of obligate breakpoints (the number of segments minus one in the order dataset) if greater than one.

**Returns:** the identifier of the best map in the frontier.

**Example:**

```
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CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rh1_true.cg
{1 haploid RH 110 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsload Data/order1_ref.cg
{2 order 110 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple...
CG> dsmergor 1 2
{3 merged by order 110 93}
#speed up likelihood computation (2-point mode)
CG> cg2pt 1

#build a Pareto frontier from scratch
CG> paretolkh 10 1 0
...
#restore multipoint likelihood computation
CG> cg2pt 0

#recompute multipoint likelihood estimates for every map in the heap
CG> cgtolerance 0.0009 0.09

#improve the Pareto frontier only near the current best map
CG> paretogreedyr 25 4 8
...
#show the best map in the improved frontier, in details
CG> paretobestprintd 1

Pareto frontier approximation (coverage: 3 / 5 = 60.00 %):
Ranges: Log10-likelihood [-1015.004,-1000.007] / BP [49,53] = 3.7493
Id:   2 BP:  53 Log10-like: -1000.007 Log10-like+bp: -1180.530
Id:   1 BP:  51 Log10-like: -1002.978 Log10-like+bp: -1176.461
Id:   0 BP:  49 Log10-like: -1015.004 Log10-like+bp: -1181.421
***...

Map 1 : log10-likelihood = -1002.98, log-e-likelihood = -2309.44
-----:

Data Set Number 1 :
```

Pos	Id	name	Markers Distance	Cumulative	Theta (%%age)	2pt LOD
1	1	UniSTS178358	11.7 cR	0.0 cR	11.0 %%	17.5
2	2	UniSTS207126	17.8 cR	11.7 cR	16.3 %%	15.1
3	3	UniSTS158776	82.5 cR	29.5 cR	56.2 %%	4.0
4	5	UniSTS164109	5.5 cR	112.0 cR	5.4 %%	20.9
5	4	UniSTS158779	14.6 cR	117.5 cR	13.6 %%	16.3
6	6	UniSTS158781	137.0 cR	132.1 cR	74.6 %%	1.8
7	110	UniSTS158909	28.9 cR	269.1 cR	25.1 %%	11.3

8	109	UniSTS178555	11.9	cR	298.0	cR	11.2	%%	15.9
9	108	UniSTS165135	11.9	cR	309.9	cR	11.2	%%	15.5
10	107	UniSTS158905	0.0	cR	321.8	cR	0.0	%%	22.0
11	106	UniSTS158906	8.9	cR	321.8	cR	8.5	%%	16.3
12	105	UniSTS178551	31.2	cR	330.7	cR	26.8	%%	8.4
13	104	UniSTS185461	26.9	cR	361.9	cR	23.6	%%	9.6
14	103	UniSTS165128	9.0	cR	388.8	cR	8.6	%%	16.7
15	102	UniSTS178540	30.7	cR	397.8	cR	26.4	%%	9.4
16	101	UniSTS178545	43.0	cR	428.4	cR	34.9	%%	7.6
17	99	UniSTS164142	0.0	cR	471.4	cR	0.0	%%	20.4
18	100	UniSTS158900	19.5	cR	471.4	cR	17.8	%%	13.7
19	97	UniSTS178531	13.9	cR	490.9	cR	13.0	%%	15.5
20	96	UniSTS178530	19.6	cR	504.9	cR	17.8	%%	12.8
21	98	UniSTS185460	63.9	cR	524.5	cR	47.2	%%	4.9
22	79	UniSTS178502	10.0	cR	588.3	cR	9.5	%%	13.8
23	80	UniSTS163269	5.5	cR	598.3	cR	5.4	%%	15.4
24	81	UniSTS158879	10.7	cR	603.8	cR	10.2	%%	14.0
25	83	UniSTS178504	3.0	cR	614.6	cR	3.0	%%	17.8
26	84	UniSTS158881	22.4	cR	617.6	cR	20.0	%%	12.5
27	89	UniSTS158883	0.0	cR	639.9	cR	0.0	%%	22.8
28	86	UniSTS185457	0.0	cR	639.9	cR	0.0	%%	23.1
29	88	UniSTS178510	0.0	cR	639.9	cR	0.0	%%	22.4
30	90	UniSTS163270	2.8	cR	639.9	cR	2.8	%%	20.3
31	85	UniSTS178506	11.7	cR	642.8	cR	11.0	%%	16.4
32	91	UniSTS178507	0.0	cR	654.4	cR	0.0	%%	23.5
33	92	UniSTS165120	15.2	cR	654.5	cR	14.1	%%	13.9
34	93	UniSTS158888	6.0	cR	669.7	cR	5.9	%%	16.6
35	94	UniSTS165123	26.7	cR	675.7	cR	23.5	%%	10.3
36	95	UniSTS178523	57.7	cR	702.4	cR	43.9	%%	6.1
37	76	UniSTS178489	0.0	cR	760.2	cR	0.0	%%	19.4
38	75	UniSTS178488	12.6	cR	760.2	cR	11.9	%%	12.1
39	73	UniSTS158872	3.6	cR	772.8	cR	3.5	%%	18.0
40	74	UniSTS158871	15.6	cR	776.4	cR	14.4	%%	13.4
41	72	UniSTS164135	3.2	cR	792.0	cR	3.1	%%	18.0
42	71	UniSTS207240	62.7	cR	795.1	cR	46.6	%%	5.8
43	77	UniSTS158875	4.1	cR	857.9	cR	4.0	%%	17.1
44	78	UniSTS178493	42.3	cR	862.0	cR	34.5	%%	7.5
45	69	UniSTS163266	22.3	cR	904.2	cR	20.0	%%	8.8
46	70	UniSTS178484	26.7	cR	926.6	cR	23.4	%%	5.8
47	68	UniSTS158867	60.8	cR	953.3	cR	45.5	%%	3.5
48	67	UniSTS158866	2.9	cR	1014.1	cR	2.9	%%	19.7
49	66	UniSTS207212	18.7	cR	1017.0	cR	17.0	%%	13.0
50	65	UniSTS178476	3.0	cR	1035.7	cR	3.0	%%	19.2
51	64	UniSTS158862	73.9	cR	1038.7	cR	52.3	%%	3.6
52	31	UniSTS178419	46.9	cR	1112.6	cR	37.5	%%	6.7
53	30	UniSTS163255	24.9	cR	1159.6	cR	22.1	%%	11.7
54	29	UniSTS158816	25.3	cR	1184.5	cR	22.3	%%	10.5
55	23	UniSTS185438	12.8	cR	1209.8	cR	12.0	%%	15.0
56	22	UniSTS178413	22.9	cR	1222.6	cR	20.5	%%	12.4
57	24	UniSTS158812	5.4	cR	1245.5	cR	5.3	%%	19.5
58	26	UniSTS163252	3.3	cR	1250.9	cR	3.3	%%	20.2
59	25	UniSTS158814	11.4	cR	1254.2	cR	10.7	%%	15.2
60	27	UniSTS158815	48.4	cR	1265.6	cR	38.4	%%	7.1
61	18	UniSTS178411	8.4	cR	1314.0	cR	8.1	%%	18.6
62	19	UniSTS158806	2.6	cR	1322.4	cR	2.6	%%	21.6
63	21	UniSTS158808	5.8	cR	1325.0	cR	5.6	%%	19.3
64	20	UniSTS178410	31.7	cR	1330.8	cR	27.1	%%	10.4
65	17	UniSTS165083	16.0	cR	1362.4	cR	14.8	%%	13.9



66	16	UniSTS158805	0.0	cR	1378.4	cR	0.0	%%	22.5
67	15	UniSTS178408	68.8	cR	1378.5	cR	49.7	%%	5.3
68	32	UniSTS178422	90.3	cR	1447.2	cR	59.5	%%	3.7
69	33	UniSTS158820	36.8	cR	1537.5	cR	30.8	%%	9.3
70	39	UniSTS158822	9.0	cR	1574.3	cR	8.6	%%	18.2
71	38	UniSTS178427	8.8	cR	1583.3	cR	8.5	%%	18.8
72	37	UniSTS178428	5.7	cR	1592.2	cR	5.6	%%	17.9
73	36	UniSTS178431	6.7	cR	1597.9	cR	6.5	%%	17.0
74	34	UniSTS178430	14.3	cR	1604.6	cR	13.3	%%	13.8
75	35	UniSTS158824	41.1	cR	1618.9	cR	33.7	%%	7.3
76	40	UniSTS165088	12.2	cR	1660.0	cR	11.5	%%	16.3
77	41	UniSTS158825	9.6	cR	1672.2	cR	9.1	%%	16.8
78	43	UniSTS158829	27.4	cR	1681.8	cR	24.0	%%	11.6
79	46	UniSTS178438	16.6	cR	1709.2	cR	15.3	%%	15.2
80	48	UniSTS165092	15.3	cR	1725.8	cR	14.2	%%	14.1
81	47	UniSTS158832	32.6	cR	1741.1	cR	27.8	%%	6.4
82	44	UniSTS164122	18.4	cR	1773.6	cR	16.8	%%	8.8
83	45	UniSTS178440	39.4	cR	1792.0	cR	32.6	%%	6.9
84	42	UniSTS178436	109.7	cR	1831.4	cR	66.6	%%	2.1
85	55	UniSTS178462	19.0	cR	1941.1	cR	17.3	%%	12.8
86	54	UniSTS178459	13.1	cR	1960.1	cR	12.3	%%	12.9
87	53	UniSTS207204	56.5	cR	1973.2	cR	43.2	%%	5.6
88	57	UniSTS163262	17.4	cR	2029.7	cR	16.0	%%	14.1
89	56	UniSTS158849	36.3	cR	2047.2	cR	30.5	%%	9.1
90	58	UniSTS158854	5.7	cR	2083.5	cR	5.5	%%	19.0
91	59	UniSTS178466	2.6	cR	2089.2	cR	2.6	%%	21.7
92	60	UniSTS164129	31.3	cR	2091.8	cR	26.9	%%	11.3
93	62	UniSTS158857	3.2	cR	2123.2	cR	3.1	%%	19.2
94	61	UniSTS165105	6.2	cR	2126.3	cR	6.0	%%	17.2
95	63	UniSTS163264	97.4	cR	2132.5	cR	62.3	%%	3.0
96	11	UniSTS158795	8.5	cR	2229.9	cR	8.1	%%	18.8
97	12	UniSTS158798	27.4	cR	2238.4	cR	24.0	%%	11.8
98	13	UniSTS178397	29.8	cR	2265.8	cR	25.8	%%	10.6
99	14	UniSTS163250	139.6	cR	2295.7	cR	75.2	%%	1.6
100	8	UniSTS178382	2.7	cR	2435.3	cR	2.7	%%	22.0
101	10	UniSTS178380	2.5	cR	2438.0	cR	2.5	%%	22.2
102	9	UniSTS158790	8.0	cR	2440.5	cR	7.6	%%	19.0
103	7	UniSTS158789	108.9	cR	2448.5	cR	66.3	%%	2.4
104	87	UniSTS165121	29.3	cR	2557.4	cR	25.4	%%	6.7
105	82	UniSTS185456	63.3	cR	2586.7	cR	46.9	%%	1.4
106	28	UniSTS207229	170.7	cR	2650.0	cR	81.9	%%	0.2
107	52	UniSTS158845	19.6	cR	2820.6	cR	17.8	%%	12.1
108	51	UniSTS178453	28.4	cR	2840.3	cR	24.7	%%	10.8
109	49	UniSTS158844	36.8	cR	2868.7	cR	30.8	%%	6.8
110	50	UniSTS178455	-----						
			2905.5	cR					

```

110 markers, log10-likelihood = -1002.98
log-e-likelihood = -2309.44
retention proba. = 0.26

```

1  
CG>

**See also:**

- `paretobestprint` (2.7.11)
- `paretoplotg` (2.7.13)

### 2.7.13 `paretoplotg`

Draw the Pareto frontier.

**Synopsis:** The `paretoplotg` command is invoked as:

- `paretoplotg` *Lambda*

**Description:** The `paretoplotg` command gives a graphical view of the Pareto frontier (that can be zoomed (Ctrl+Up), printed or saved (right mouse click)). It draws the traditional and comparative mapping criteria for the maps in the frontier. The red triangle corresponds to the best map. By clicking on any point in the frontier, a comparative mapping view can be obtained between the corresponding map and the reference genome. The distance between adjacent markers can be fixed or proportional, see the option menu with a right mouse click. This important command allows to assess the quality of the Pareto frontier and the comparative mapping strategy. First, the frontier should be dense, i.e. having at most one map per number of breakpoints, and without too many dominated maps (represented by the green points) (if not, then try to increase the *NbResolution* parameter in `paretolkh` and the *Anytime* parameter in `paretogreedy`). Secondly, the shapes of the two loglikelihood curves show the respective contributions of the biological data and of the reference order in the selection of the best map. If the two curves are almost identical, then the contribution of the reference order is weak. On the contrary, if the curve of the comparative mapping criterion decreases rapidly, then the contribution of the reference order is strong. A flat curve means that the selection of the best map which maximizes the comparative mapping criterion is not very reliable.

**Arguments:**

- *Lambda* : it corresponds to the expected number of breakpoints between the true order and the reference order. If unknown, it should be set to 1 or to the minimum number of obligate breakpoints (the number of segments minus one in the order dataset) if greater than one.

**Returns:** Nothing.

**See also:**

- `paretobestprint` (2.7.11)

### 2.7.14 `paretosave`

Save the pareto frontier in a file that can be later used to restore the current state (data sets loaded, markers merged, frontier loaded into the heap).

**Synopsis:** The `paretosave` command is invoked either as:

- `paretosave` *Options*
- `paretosave` *FileName*

**Description:** The `paretosave` command enables to save a Pareto frontier to a Tcl script. The state of the session is defined by all the data sets including merged datasets, the loci selected, the merged loci, and all the map stored in the frontier. By running the Tcl script all the entities mentioned before will be regenerated. To restore a session, type the command `source` followed by the name of the file.

Be careful, only the path to the the data sets file are kept by the script file. They may be relatives, and your script will depend on the working location. Nevertheless, the script is editable.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *FileName*: the name (including its path) of the file to which you want CarthaGene to save the frontier.

### 2.7.15 Computing the number of breakpoints

The number of breakpoints between a map (respectively a biological dataset marker ordering) and a reference order is computed by the `mapbp` (respectively `dsbp`) command. All the markers which do not appear in the reference order are not taken into account when computing the exact number of breakpoints. This number of breakpoints is the number of adjacent markers in an order which are not adjacent in the reference order. Two adjacent markers from two different chromosomes in the reference genome always count for one (obligate) breakpoint. For instance, the order “1, 4, 3, 2, 5, 7, 6, 8, 9, 10” has only three breakpoints with the reference order “(chr01)1,2,3,4,5,8,(chr02)9,10”: the breakpoints are 1-4, 2-5, and 8-9 (they are not on the same chromosome in the reference genome). 5-7 and 6-8 are not breakpoints because markers 6 and 7 do not appear in the reference order.

### 2.7.16 `mapbp`

Compute the number of breakpoints between one order data set and a map.

**Synopsis:** The `mapbp` command is invoked either:

- `mapbp Options`
- `mapbp SetId MapId`

**Description:** The `mapbp` command computes the number of breakpoints between a map and a reference order. All the markers which do not appear in the reference order are not taken into account when computing the exact number of breakpoints. The number of breakpoints is the number of adjacent markers in an order which are not adjacent in the reference order. Two adjacent markers from two different chromosomes in the reference genome always count for one (obligate) breakpoint.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *SetId*: the numerical id of the order dataset (see `dsinfo`).
- *MapId*: the numerical id of the map in the heap.

**Returns:** number of breakpoints.

### Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/rh1_true.cg  
{1 haploid RH 110 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user...  
CG> dsload Data/order1_ref.cg  
{2 order 110 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple...  
CG> dsmergor 1 2  
{3 merged by order 110 93}  
CG> sem  
...  
CG> mapbp 2 0  
6  
CG>
```

### See also:

- dsbp (2.7.17)

## 2.7.17 dsbp

Compute the number of breakpoints between one order data set and one biological data set.

**Synopsis:** The dsbp command is invoked either:

- dsbp *Options*
- dsbp *SetId1 SetId2*

**Description:** The dsbp command computes the number of breakpoints between a biological dataset (the order of the markers is the original order in the file) and a reference order. All the markers which do not appear in both datasets are not taken into account when computing the exact number of breakpoints. The number of breakpoints is the number of adjacent markers in an order which are not adjacent in the reference order. Two adjacent markers from two different chromosomes in the reference genome always count for one (obligate) breakpoint.

### Arguments:

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *SetId1*: the numerical id of the order dataset (see dsinfo).
- *SetId2*: the numerical id of the biological dataset (see dsinfo).

**Returns:** number of breakpoints.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/rhl_true.cg
{1 haploid RH 110 93 /home/ubuntu/carthagene/build/linux64/Release/doc/user...
CG> dsload Data/order1_ref.cg
{2 order 110 /home/ubuntu/carthagene/build/linux64/Release/doc/user/exemple...
CG> dsmergor 1 2
{3 merged by order 110 93}
CG> dsbp 2 1
6
CG>
```

**See also:**

- mapbp (2.7.16)

## 2.8 System commands

There are several commands in CAR<sub>T</sub>HAGENE that deal with several system aspects. They can affect the verbosity of CAR<sub>T</sub>HAGENE, gives some basic statistics on CAR<sub>T</sub>HAGENE behavior or restart the software to forget all data loaded. A more detailed description of each command is given below.

### 2.8.1 cgout

Saves the output of CarthaGène to a file. This is different from `cgsave` that allows to save the current state of CarthaGène (in order to later restore it). `cgout` is intended merely to build log file.

**Synopsis:** The `cgout` command is invoked either as:

- `cgout Options`
- `cgout FilePath`

**Description:** The `cgout` command enables to save the output of the session in a file specified by the *FilePath* argument. If the file already exist, the output is appened to the end of the file. If a output file was already specified, the old log file is closed and the output goes to the new one. This process is terminated by using a empty string or by ending CarthaGene.

Only the inputs and outputs of the correct commands of Carthagene will be saved. You may want to launch the shell with the `tee` command ( under Unix) to keep a complete log (`tcsh | tee logfile`).

## Arguments:

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *FilePath*: the path to a valid text file existing or not.

## Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -291.76
-----:
Set : Marker List ...
1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS...

CG> exec rm -f "carthagene.log"
...
CG> cgout "carthagene.log"

CG> heaprintd
...
CG> cgout ""

CG> exec cat "carthagene.log"

CG_log> heaprintd

Map 0 : log10-likelihood = -291.76, log-e-likelihood = -671.79
-----:

Data Set Number 1 :
```

Pos	Id	name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	1	MS1		19.5 cM	0.0 cM	16.8 cM	16.2 %%	15.7
2	2	MS2		0.6 cM	19.5 cM	0.6 cM	0.6 %%	47.6
3	3	MS3		5.8 cM	20.1 cM	5.5 cM	5.5 %%	35.1
4	4	MS4		3.7 cM	25.9 cM	3.6 cM	3.5 %%	21.1
5	5	MS5		3.7 cM	29.6 cM	3.6 cM	3.6 %%	15.4
6	6	MS6		1.6 cM	33.3 cM	1.6 cM	1.6 %%	17.3
7	7	MS7		6.7 cM	34.9 cM	6.3 cM	6.3 %%	35.1
8	8	MS8		2.2 cM	41.6 cM	2.2 cM	2.2 %%	40.8
9	9	MS9		3.0 cM	43.8 cM	2.9 cM	2.9 %%	7.2
10	10	MS10		5.4 cM	46.8 cM	5.1 cM	5.1 %%	3.6
11	11	MS11		8.6 cM	52.2 cM	7.9 cM	7.9 %%	10.9

12	12	MS12	0.0 cM	60.7 cM	0.0 cM	0.0 %%	18.7
13	13	MS13	0.0 cM	60.7 cM	0.0 cM	0.0 %%	6.0
14	14	MS14	5.8 cM	60.7 cM	5.5 cM	5.5 %%	0.0
15	15	MS15	4.6 cM	66.6 cM	4.4 cM	4.4 %%	26.6
16	16	MS16	26.1 cM	71.1 cM	21.6 cM	20.3 %%	6.3
17	17	MS17	0.0 cM	97.2 cM	0.0 cM	0.0 %%	16.0
18	18	MS18	4.9 cM	97.2 cM	4.7 cM	4.6 %%	27.1
19	19	MS19	3.0 cM	102.1 cM	2.9 cM	2.9 %%	34.8
20	20	MS20	-----		-----		
			105.1 cM		95.0 cM		

```

20 markers, log10-likelihood = -291.76
log-e-likelihood = -671.79

```

```

EM calls:
  Set 1 : 2 (1,0)
CPU Time (secs): 0.00
Maps within -3.0: 1

```

```

CG_log> cgout
CG>

```

## 2.8.2 cgversion

Returns the release version of the software.

**Synopsis:** The `cgversion` command is invoked as either one of :

- `cgversion Options`
- `cgversion`

**Description:** returns the release version of the software.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.

**Returns:** nothing.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> cgversion
```

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG>
```

### 2.8.3 cglicense

Obsolete. Initially used to unlock the software using a software key.

**Synopsis:** The `cglicense` command is invoked either as:

- `cglicense Options`
- `cglicense key`

**Description:** Initially, the use of the software Carthagene was limited to simple backcross data sets until it was “unlocked” using this command with a free software key. This is no longer true since release 0.99.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *key*: a free software key.

**Returns:** nothing

**Example:**

```
CG> cglicense FGTZMBTBCTGWT
```

### 2.8.4 cgstat

Displays some benchmarking statistics on CarthaGene and the Heap.

**Synopsis:** The `cgstat` command is invoked either as:

- `cgstat Options`
- `cgstat LOD-Threshold`



**Description:** The command `cgstat` displays some basic statistics on the software and the contents of the heap. It reports the total CPU-time consumed, the number of calls to the EM (Expectation/Maximization) algorithm and the number of maps in the heap within *LOD-Threshold* of the best known map in the heap.

For internal use only: if the data-set loaded is identified as a randomly generated test data-set, further statistics are reported: difference in log-likelihood of the best known map with the log-likelihood of the order used to generate the data, at what cpu-time stamp this map was found and if it is identical to the order used to generate the data.

### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *LOD-Threshold*: maximum difference in loglikelihood with the best known map.

**Returns:** a list of these different statistics (some may be unapplicable when the data set used is not a benchmarking random data-set).

- a boolean that indicates whether the best map found is the correct (model) map.
- the total cpu-time used
- the difference of loglikelihood between the best maporder and the “true” order.
- the cpu-time stamp of the best known map.
- the number of maps in the heap whose loglikelihood is within *LOD-Threshold* of the best map.
- the number of EM calls overall.

### Example:

```
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under certain conditions. See the License file for information.

Type 'help' for help.

# we load a dataset
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
#compute groups
CG> group 0.1 7
...
#and select group 4
CG> mrkselset [groupget 4]
...
# compute a first map
CG> nicemapd
...
# check the quality of this order
CG> flips 2 0 0
...
```

```
#check some statistics and ask for the number of maps within 1 of the optimum
CG> cgstat 1
```

```
Map 8 : log10-likelihood = -129.39, log-e-likelihood = -297.93
-----;
```

```
Data Set Number 1 :
```

Pos	Id name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	2	MS2	0.6 cM	0.0 cM	0.6 cM	0.6 %%	47.6
2	3	MS3	5.8 cM	0.6 cM	5.5 cM	5.5 %%	35.1
3	4	MS4	3.6 cM	6.4 cM	3.5 cM	3.5 %%	21.1
4	5	MS5	3.7 cM	10.1 cM	3.6 cM	3.6 %%	15.4
5	6	MS6	1.6 cM	13.8 cM	1.6 cM	1.6 %%	17.3
6	7	MS7	6.7 cM	15.4 cM	6.3 cM	6.3 %%	35.1
7	8	MS8	2.5 cM	22.1 cM	2.5 cM	2.5 %%	7.4
8	10	MS10	0.0 cM	24.6 cM	0.0 cM	0.0 %%	7.2
9	9	MS9	-----		-----		
			24.6 cM		23.6 cM		

```
9 markers, log10-likelihood = -129.39
log-e-likelihood = -297.93
```

```
Total CPU Time (secondes): 0.00
Number of calls to EM: 28
# of maps within -130.390165: 1
Current best LogLike is -129.390165 and worst is -153.374826
Reliability Threshold = 1e+100
Tolerance Threshold1 = 0.1
Tolerance Threshold2 = 0.001
{1 0.000000 1 0.000000 0.000000 1 28}
```

#### See also:

- [cgrestart \(2.8.5\)](#)
- [heaprint \(2.4.4\)](#)

## 2.8.5 cgrestart

Reinitializes CarthaGene.

**Synopsis:** The `cgrestart` command is invoked either as:

- `cgrestart Options`
- `cgrestart`

**Description:** The `cgrestart` command completely reinitialises the software. All loaded data-sets, maps... are erased from memory and a new session can be started.

**Arguments :**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.

**Returns:** nothing

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).

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under certain conditions. See the License file for information.

Type 'help' for help.

# we load a dataset
CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
# change our mind and zap everything
CG> cgrestart

# no dataset is loaded now
CG> dsinfo

Data Sets :
-----:
ID          Data Type   markers individuals      filename constraints...

CG>
```

**See also:**

- `cgstat` (2.8.4)

**2.8.6 quietset**

Sets the conciseness of the output of several commands.

**Synopsis:** The `quietset` command is invoked either as:

- `quietset Options`
- `quietset level`

**Description:**

**Arguments:**

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *level*: the level of quietness (0 or 1).

**Returns:** nothing.

**Example:**

```
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under certain conditions. See the License file for information.

Type 'help' for help.

CG> dsload Data/bc.cg
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
CG> sem

Map -1 : log10-likelihood = -291.76
-----:
Set : Marker List ...
    1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS...

CG> quietset 1

CG> sem
```

**See also:**

- `verbset` (2.8.7)

**2.8.7 verbset**

Sets the verbosity of the output of several commands.

**Synopsis:** The `verbset` command is invoked either as:

- `verbset Options`
- `verbset level`

**Description:**

## Arguments:

- *Options* : -u to obtain the synopsis of the normal use, -h to print a one line description, -H to print a short help.
- *level*: the level of verbosity (0, 1 or 2).

**Returns:** nothing.

## Example:

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
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```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

Type 'help' for help.

```
CG> dsload Data/bc.cg  
{1 f2 backcross 20 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...  
CG> sem
```

```
Map -1 : log10-likelihood = -291.76
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS1 MS2 MS3 MS4 MS5 MS6 MS7 MS8 MS9 MS10 MS11 MS12 MS13 MS14 MS15 MS...
```

```
CG> verbset 2
```

```
CG> sem
```

```
Map -1 : log10-likelihood = -291.76, log-e-likelihood = -671.79
```

```
-----:
```

```
Data Set Number 1 :
```

Pos	Id	name	Markers	Distance Haldane	Cumulative Haldane	Distance Kosambi	Theta (%%age)	2pt LOD
1	1	MS1		19.5 cM	0.0 cM	16.8 cM	16.2 %%	15.7
2	2	MS2		0.6 cM	19.5 cM	0.6 cM	0.6 %%	47.6
3	3	MS3		5.8 cM	20.1 cM	5.5 cM	5.5 %%	35.1
4	4	MS4		3.7 cM	25.9 cM	3.6 cM	3.5 %%	21.1
5	5	MS5		3.7 cM	29.6 cM	3.6 cM	3.6 %%	15.4
6	6	MS6		1.6 cM	33.3 cM	1.6 cM	1.6 %%	17.3
7	7	MS7		6.7 cM	34.9 cM	6.3 cM	6.3 %%	35.1
8	8	MS8		2.2 cM	41.6 cM	2.2 cM	2.2 %%	40.8
9	9	MS9		3.0 cM	43.8 cM	2.9 cM	2.9 %%	7.2
10	10	MS10		5.4 cM	46.8 cM	5.1 cM	5.1 %%	3.6
11	11	MS11		8.6 cM	52.2 cM	7.9 cM	7.9 %%	10.9
12	12	MS12		0.0 cM	60.7 cM	0.0 cM	0.0 %%	18.7
13	13	MS13		0.0 cM	60.7 cM	0.0 cM	0.0 %%	6.0
14	14	MS14		5.8 cM	60.7 cM	5.5 cM	5.5 %%	0.0
15	15	MS15		4.6 cM	66.6 cM	4.4 cM	4.4 %%	26.6
16	16	MS16		26.1 cM	71.1 cM	21.6 cM	20.3 %%	6.3

17	17	MS17	0.0 cM	97.2 cM	0.0 cM	0.0 %%	16.0
18	18	MS18	4.9 cM	97.2 cM	4.7 cM	4.6 %%	27.1
19	19	MS19	3.0 cM	102.1 cM	2.9 cM	2.9 %%	34.8
20	20	MS20	-----		-----		
			105.1 cM		95.0 cM		

```

20 markers, log10-likelihood = -291.76
log-e-likelihood = -671.79

```

#### See also:

- `quietset` (2.8.6)

## 2.8.8 `cgsave`

Saves the state of the current session in a file that can be later used to restore the current state (data sets loaded, markers merged, heap state). This is different from `cgout` which allows to save the output of the commands issued as they are executed.

**Synopsis:** The `cgsave` command is invoked either as:

- `cgsave Options`
- `cgsave FilePath`

**Description:** The `cgsave` command enable to save a CarthaGene session state to a Tcl script. The state of the session is defined by all the data sets including merged datasets, the loci selected, the merged loci, and all the map stored in the heap. By running the tcl script all the entities mentioned before will be regenerated. To restore a session, type the command `source` followed by the name of the file.

Be careful, only the path to the the data sets file are kept by the script file. They may be relatives, and your script will depend on the working location. Nevertheless, the script is editable.

#### Arguments:

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *FilePath*: the path of the file to which you want CarthaGene to save the session.

#### Example:

```

...
CG> cgsave secur0.tcl
The file secure0.tcl already exist, replacing it? ([y] or n):y
Your session has been successfully saved.
To restore it, type : source secure0.tcl
CG> cgrestart
CG> source secur0.tcl
...

```

**See also:**

- 
- `cgrestart` (2.8.5)
- 
- `cgout` (2.8.1)

## 2.8.9 `cgexport`

**Synopsis:** The `cgexport` command is invoked either as:

- `cgexport Options`
- `cgexport fileName mapName chromosomeName`

**Description:** The `cgexport` command saves the current best map of the heap to a file. If the chosen file already exist, the command will (after asking for authorization) append the current map to the end of the existing file. Two output formats are simultaneously created: a MapMaker format is used to output maps in the file whose *fileName* is given while an XML format file (designed to interact with existing BioMercator and MCQTL software, see <http://www.genoplante.com>) is generated in a file with the *fileName* extended with `.xml`.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *fileName*: the path of the file to which you want to save the map.
- *mapName*: any identifier you want to associate with the map produced.
- *chromosomeName*: any identifier you want to associate with the chromosome mapped.

**Example:**

```
CarthaGene version 1.2, Copyright (c) 1997-2008 (INRA).
```

```
CarthaGene comes with ABSOLUTELY NO WARRANTY.
```

```
CarthaGene is free software. You are welcome to redistribute it,  
under certain conditions. See the License file for information.
```

```
Type 'help' for help.
```

```
CG> dsload Data/bcl.cg
```

```
{1 f2 backcross 17 208 /home/ubuntu/carthagene/build/linux64/Release/doc/us...
```

```
CG> sem
```

```
Map -1 : log10-likelihood = -479.22
```

```
-----:
```

```
Set : Marker List ...
```

```
1 : MS4 MS5 MS13 MS6 MS11 MS17 MS16 MS8 MS7 MS2 MS3 MS9 MS15 MS12 MS20 MS1\  
9 MS1
```

```
CG> cgexport StupidMap MyMap MyChromosome
export successful!
```

```
CG>
```

**See also:**

- 
- `cgrestart` (2.8.8)
- 
- `cgout` (2.8.1)

## 2.8.10 `cg2pt`

Compute approximated likelihoods based on 2-point estimation data.

**Synopsis:** The `cg2pt` command is invoked as either:

- `cg2pt Options`
- `cg2pt Mode`

**Description:** The `cg2pt` command allows fast likelihood computations based on 2-point estimation data when *Mode* is set to a value different from zero. Otherwise, exact multipoint likelihood computations are performed by the EM algorithm. The fast mode should be chosen with care because it does a poor approximation in the case of multiple datasets merged by order (`dsmergor`) and also when there are many missing data in the datasets.

**Arguments:**

- *Options* : `-u` to obtain the synopsis of the normal use, `-h` to print a one line description, `-H` to print a short help.
- *Mode*: if set to 1, then enter in fast likelihood computation mode ; if set to 0, then enter in normal multipoint likelihood computation mode.

**See also:**

- `paretolkh` (2.7.4)



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