

relax

Version 1.3.13



A program for NMR relaxation  
data analysis

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# Contents

|          |                                            |           |
|----------|--------------------------------------------|-----------|
| <b>1</b> | <b>Introduction</b>                        | <b>1</b>  |
| 1.1      | Program features                           | 1         |
| 1.1.1    | Literature                                 | 1         |
| 1.1.2    | Supported NMR theories                     | 2         |
| 1.1.3    | Data analysis tools                        | 2         |
| 1.1.4    | Data visualisation                         | 3         |
| 1.1.5    | Interfacing with other programs            | 3         |
| 1.1.6    | The user interfaces (UI)                   | 3         |
| 1.2      | How to use relax                           | 4         |
| 1.2.1    | The prompt                                 | 4         |
| 1.2.2    | Python                                     | 4         |
| 1.2.3    | User functions                             | 6         |
| 1.2.4    | The help system                            | 6         |
| 1.2.5    | Tab completion                             | 6         |
| 1.2.6    | The data pipe                              | 7         |
| 1.2.7    | Scripting                                  | 8         |
| 1.2.8    | Sample scripts                             | 9         |
| 1.2.9    | The test suite                             | 10        |
| 1.2.10   | The GUI                                    | 10        |
| 1.2.11   | Access to the internals of relax           | 11        |
| 1.3      | Usage of the name relax                    | 11        |
| <b>2</b> | <b>Installation instructions</b>           | <b>13</b> |
| 2.1      | Dependencies                               | 13        |
| 2.2      | Installation                               | 13        |
| 2.2.1    | The precompiled versus source distribution | 13        |
| 2.2.2    | Installation on GNU/Linux                  | 14        |
| 2.2.3    | Installation on MS Windows                 | 14        |
| 2.2.4    | Installation on Mac OS X                   | 15        |
| 2.2.5    | Installation on your OS                    | 15        |
| 2.2.6    | Running a non-compiled version             | 15        |
| 2.3      | Optional programs                          | 15        |
| 2.3.1    | Grace                                      | 15        |
| 2.3.2    | OpenDX                                     | 15        |
| 2.3.3    | Molmol                                     | 16        |
| 2.3.4    | PyMOL                                      | 16        |
| 2.3.5    | Dasha                                      | 16        |
| 2.3.6    | Modelfree4                                 | 16        |
| <b>3</b> | <b>Open source infrastructure</b>          | <b>17</b> |

|          |                                                                   |           |
|----------|-------------------------------------------------------------------|-----------|
| 3.1      | The relax web sites . . . . .                                     | 17        |
| 3.2      | The mailing lists . . . . .                                       | 17        |
| 3.2.1    | relax-announce . . . . .                                          | 17        |
| 3.2.2    | relax-users . . . . .                                             | 18        |
| 3.2.3    | relax-devel . . . . .                                             | 18        |
| 3.2.4    | relax-commits . . . . .                                           | 18        |
| 3.2.5    | Replying to a message . . . . .                                   | 18        |
| 3.3      | Reporting bugs . . . . .                                          | 18        |
| 3.4      | Latest sources – the relax repositories . . . . .                 | 19        |
| 3.5      | News . . . . .                                                    | 19        |
| 3.6      | The relax distribution archives . . . . .                         | 19        |
| <b>4</b> | <b>Calculating the NOE</b> . . . . .                              | <b>21</b> |
| 4.1      | Introduction . . . . .                                            | 21        |
| 4.2      | The sample script . . . . .                                       | 21        |
| 4.3      | Initialisation of the data pipe . . . . .                         | 22        |
| 4.4      | Loading the data . . . . .                                        | 22        |
| 4.5      | Setting the errors . . . . .                                      | 23        |
| 4.6      | Unresolved residues . . . . .                                     | 23        |
| 4.7      | The NOE . . . . .                                                 | 24        |
| 4.8      | Viewing the results . . . . .                                     | 24        |
| <b>5</b> | <b>Relaxation curve-fitting</b> . . . . .                         | <b>27</b> |
| 5.1      | Introduction . . . . .                                            | 27        |
| 5.2      | The sample script . . . . .                                       | 27        |
| 5.3      | Initialisation of the data pipe and loading of the data . . . . . | 28        |
| 5.4      | The rest of the setup . . . . .                                   | 29        |
| 5.5      | Optimisation . . . . .                                            | 30        |
| 5.6      | Error analysis . . . . .                                          | 30        |
| 5.7      | Finishing off . . . . .                                           | 31        |
| <b>6</b> | <b>Model-free analysis</b> . . . . .                              | <b>33</b> |
| 6.1      | Theory . . . . .                                                  | 33        |
| 6.1.1    | The chi-squared function – $\chi^2(\theta)$ . . . . .             | 33        |
| 6.1.2    | The transformed relaxation equations – $R_i(\theta)$ . . . . .    | 33        |
| 6.1.3    | The relaxation equations – $R'_i(\theta)$ . . . . .               | 34        |
| 6.1.4    | The spectral density functions – $J(\omega)$ . . . . .            | 34        |
| 6.1.5    | Brownian rotational diffusion . . . . .                           | 35        |
| 6.1.6    | The model-free models . . . . .                                   | 37        |
| 6.1.7    | Model-free optimisation theory . . . . .                          | 38        |
| 6.2      | Optimisation of a single model-free model . . . . .               | 49        |
| 6.2.1    | The sample script . . . . .                                       | 49        |
| 6.2.2    | The rest . . . . .                                                | 50        |
| 6.3      | Optimisation of all model-free models . . . . .                   | 50        |
| 6.3.1    | The sample script . . . . .                                       | 50        |
| 6.3.2    | The rest . . . . .                                                | 51        |
| 6.4      | Model-free model selection . . . . .                              | 51        |
| 6.4.1    | The sample script . . . . .                                       | 51        |
| 6.4.2    | The rest . . . . .                                                | 52        |
| 6.5      | The methodology of Mandel et al., 1995 . . . . .                  | 52        |

|          |                                                               |           |
|----------|---------------------------------------------------------------|-----------|
| 6.6      | The diffusion seeded paradigm . . . . .                       | 52        |
| 6.7      | The new model-free optimisation protocol . . . . .            | 55        |
| <b>7</b> | <b>Reduced spectral density mapping</b>                       | <b>57</b> |
| <b>8</b> | <b>Values, gradients, and Hessians</b>                        | <b>59</b> |
| 8.1      | Introduction . . . . .                                        | 59        |
| 8.2      | Minimisation concepts . . . . .                               | 59        |
| 8.2.1    | The function value . . . . .                                  | 59        |
| 8.2.2    | The gradient . . . . .                                        | 59        |
| 8.2.3    | The Hessian . . . . .                                         | 60        |
| 8.3      | The four parameter combinations . . . . .                     | 60        |
| 8.3.1    | Optimisation of the model-free models . . . . .               | 60        |
| 8.3.2    | Optimisation of the local $\tau_m$ models . . . . .           | 61        |
| 8.3.3    | Optimisation of the diffusion tensor parameters . . . . .     | 61        |
| 8.3.4    | Optimisation of the global model $\mathfrak{S}$ . . . . .     | 61        |
| 8.4      | Construction of the values, gradients, and Hessians . . . . . | 62        |
| 8.4.1    | The sum of chi-squared values . . . . .                       | 62        |
| 8.4.2    | Construction of the gradient . . . . .                        | 62        |
| 8.4.3    | Construction of the Hessian . . . . .                         | 64        |
| 8.5      | The value, gradient, and Hessian dependency chain . . . . .   | 64        |
| 8.6      | The $\chi^2$ value, gradient, and Hessian . . . . .           | 64        |
| 8.6.1    | The $\chi^2$ value . . . . .                                  | 64        |
| 8.6.2    | The $\chi^2$ gradient . . . . .                               | 66        |
| 8.6.3    | The $\chi^2$ Hessian . . . . .                                | 66        |
| 8.7      | The $R_i(\theta)$ values, gradients, and Hessians . . . . .   | 67        |
| 8.7.1    | The $R_i(\theta)$ values . . . . .                            | 67        |
| 8.7.2    | The $R_i(\theta)$ gradients . . . . .                         | 67        |
| 8.7.3    | The $R_i(\theta)$ Hessians . . . . .                          | 67        |
| 8.8      | $R'_i(\theta)$ values, gradients, and Hessians . . . . .      | 68        |
| 8.8.1    | Components of the $R'_i(\theta)$ equations . . . . .          | 68        |
| 8.8.2    | $R'_i(\theta)$ values . . . . .                               | 71        |
| 8.8.3    | $R'_i(\theta)$ gradients . . . . .                            | 71        |
| 8.8.4    | $R'_i(\theta)$ Hessians . . . . .                             | 72        |
| 8.9      | Model-free analysis . . . . .                                 | 76        |
| 8.9.1    | The model-free equations . . . . .                            | 76        |
| 8.9.2    | The original model-free gradient . . . . .                    | 77        |
| 8.9.3    | The original model-free Hessian . . . . .                     | 78        |
| 8.9.4    | The extended model-free gradient . . . . .                    | 81        |
| 8.9.5    | The extended model-free Hessian . . . . .                     | 83        |
| 8.9.6    | The alternative extended model-free gradient . . . . .        | 88        |
| 8.9.7    | The alternative extended model-free Hessian . . . . .         | 90        |
| 8.10     | Ellipsoidal diffusion tensor . . . . .                        | 95        |
| 8.10.1   | The diffusion equation of the ellipsoid . . . . .             | 95        |
| 8.10.2   | The weights of the ellipsoid . . . . .                        | 95        |
| 8.10.3   | The weight gradients of the ellipsoid . . . . .               | 96        |
| 8.10.4   | The weight Hessians of the ellipsoid . . . . .                | 98        |
| 8.10.5   | The correlation times of the ellipsoid . . . . .              | 104       |
| 8.10.6   | The correlation time gradients of the ellipsoid . . . . .     | 104       |

|          |                                                                                 |            |
|----------|---------------------------------------------------------------------------------|------------|
| 8.10.7   | The correlation time Hessians of the ellipsoid . . . . .                        | 106        |
| 8.11     | Spheroidal diffusion tensor . . . . .                                           | 108        |
| 8.11.1   | The diffusion equation of the spheroid . . . . .                                | 108        |
| 8.11.2   | The weights of the spheroid . . . . .                                           | 108        |
| 8.11.3   | The weight gradients of the spheroid . . . . .                                  | 109        |
| 8.11.4   | The weight Hessians of the spheroid . . . . .                                   | 109        |
| 8.11.5   | The correlation times of the spheroid . . . . .                                 | 110        |
| 8.11.6   | The correlation time gradients of the spheroid . . . . .                        | 110        |
| 8.11.7   | The correlation time Hessians of the spheroid . . . . .                         | 110        |
| 8.12     | Spherical diffusion tensor . . . . .                                            | 112        |
| 8.12.1   | The diffusion equation of the sphere . . . . .                                  | 112        |
| 8.12.2   | The weight of the sphere . . . . .                                              | 112        |
| 8.12.3   | The weight gradient of the sphere . . . . .                                     | 112        |
| 8.12.4   | The weight Hessian of the sphere . . . . .                                      | 113        |
| 8.12.5   | The correlation time of the sphere . . . . .                                    | 113        |
| 8.12.6   | The correlation time gradient of the sphere . . . . .                           | 113        |
| 8.12.7   | The correlation time Hessian of the sphere . . . . .                            | 113        |
| 8.13     | Ellipsoidal dot product derivatives . . . . .                                   | 114        |
| 8.13.1   | The dot product of the ellipsoid . . . . .                                      | 114        |
| 8.13.2   | The dot product gradient of the ellipsoid . . . . .                             | 114        |
| 8.13.3   | The dot product Hessian of the ellipsoid . . . . .                              | 116        |
| 8.14     | Spheroidal dot product derivatives . . . . .                                    | 118        |
| 8.14.1   | The dot product of the spheroid . . . . .                                       | 118        |
| 8.14.2   | The dot product gradient of the spheroid . . . . .                              | 118        |
| 8.14.3   | The dot product Hessian of the spheroid . . . . .                               | 118        |
| <b>9</b> | <b>relax development</b>                                                        | <b>121</b> |
| 9.1      | Version control using Subversion . . . . .                                      | 121        |
| 9.2      | Coding conventions . . . . .                                                    | 122        |
| 9.2.1    | Indentation . . . . .                                                           | 122        |
| 9.2.2    | Doc strings . . . . .                                                           | 122        |
| 9.2.3    | Variable, function, and class names . . . . .                                   | 123        |
| 9.2.4    | Whitespace . . . . .                                                            | 125        |
| 9.2.5    | Comments . . . . .                                                              | 126        |
| 9.3      | Submitting changes to the relax project . . . . .                               | 126        |
| 9.3.1    | Submitting changes as a patch . . . . .                                         | 126        |
| 9.3.2    | Modification of official releases – creating patches with diff . . . . .        | 127        |
| 9.3.3    | Modification of the latest sources – creating patches with Subversion . . . . . | 127        |
| 9.4      | Committers . . . . .                                                            | 127        |
| 9.4.1    | Becoming a committer . . . . .                                                  | 127        |
| 9.4.2    | Joining Gna! . . . . .                                                          | 128        |
| 9.4.3    | Joining the relax project . . . . .                                             | 128        |
| 9.4.4    | Format of the commit logs . . . . .                                             | 128        |
| 9.4.5    | Discussing major changes . . . . .                                              | 130        |
| 9.5      | Branches . . . . .                                                              | 130        |
| 9.5.1    | Branch creation . . . . .                                                       | 130        |
| 9.5.2    | Keeping the branch up to date using <code>svnmerge.py</code> . . . . .          | 130        |
| 9.5.3    | Merging the branch back into the main line . . . . .                            | 131        |
| 9.6      | The SCons build system . . . . .                                                | 132        |

|           |                                                     |            |
|-----------|-----------------------------------------------------|------------|
| 9.6.1     | SCons help                                          | 132        |
| 9.6.2     | C module compilation                                | 132        |
| 9.6.3     | Compilation of the user manual (PDF version)        | 132        |
| 9.6.4     | Compilation of the user manual (HTML version)       | 132        |
| 9.6.5     | Compilation of the API documentation (HTML version) | 132        |
| 9.6.6     | Making distribution archives                        | 133        |
| 9.6.7     | Cleaning up                                         | 133        |
| 9.7       | The core design of relax                            | 133        |
| 9.7.1     | The divisions of relax's source code                | 134        |
| 9.7.2     | The major components of relax                       | 134        |
| 9.8       | The mailing lists                                   | 137        |
| 9.8.1     | Private vs. public messages                         | 137        |
| 9.9       | The bug, task, and support request trackers         | 137        |
| 9.9.1     | Submitting a bug report                             | 137        |
| 9.9.2     | Assigning an issue to yourself                      | 138        |
| 9.9.3     | Closing an issue                                    | 138        |
| 9.10      | Links, links, and more links                        | 138        |
| 9.10.1    | Navigation                                          | 138        |
| 9.10.2    | Search engine indexing                              | 139        |
| <b>10</b> | <b>Alphabetical listing of user functions</b>       | <b>141</b> |
| 10.1      | A warning about the formatting                      | 141        |
| 10.2      | The list of functions                               | 141        |
| 10.2.1    | The synopsis                                        | 141        |
| 10.2.2    | Defaults                                            | 141        |
| 10.2.3    | Docstring sectioning                                | 142        |
| 10.2.4    | align_tensor.copy()                                 | 143        |
| 10.2.5    | align_tensor.delete()                               | 143        |
| 10.2.6    | align_tensor.display()                              | 143        |
| 10.2.7    | align_tensor.fix()                                  | 143        |
| 10.2.8    | align_tensor.init()                                 | 144        |
| 10.2.9    | align_tensor.matrix_angles()                        | 144        |
| 10.2.10   | align_tensor.reduction()                            | 145        |
| 10.2.11   | align_tensor.set_domain()                           | 145        |
| 10.2.12   | align_tensor.svd()                                  | 145        |
| 10.2.13   | angle_diff_frame()                                  | 146        |
| 10.2.14   | bmr.b.citation()                                    | 146        |
| 10.2.15   | bmr.b.display()                                     | 147        |
| 10.2.16   | bmr.b.read()                                        | 147        |
| 10.2.17   | bmr.b.script()                                      | 148        |
| 10.2.18   | bmr.b.software()                                    | 149        |
| 10.2.19   | bmr.b.software_select()                             | 149        |
| 10.2.20   | bmr.b.thiol_state()                                 | 150        |
| 10.2.21   | bmr.b.write()                                       | 150        |
| 10.2.22   | calc()                                              | 150        |
| 10.2.23   | consistency_tests.set_freq()                        | 151        |
| 10.2.24   | dasha.create()                                      | 151        |
| 10.2.25   | dasha.execute()                                     | 151        |
| 10.2.26   | dasha.extract()                                     | 152        |

|         |                              |     |
|---------|------------------------------|-----|
| 10.2.27 | deselect.all()               | 152 |
| 10.2.28 | deselect.read()              | 152 |
| 10.2.29 | deselect.reverse()           | 153 |
| 10.2.30 | deselect.spin()              | 153 |
| 10.2.31 | diffusion_tensor.copy()      | 154 |
| 10.2.32 | diffusion_tensor.delete()    | 154 |
| 10.2.33 | diffusion_tensor.display()   | 154 |
| 10.2.34 | diffusion_tensor.init()      | 155 |
| 10.2.35 | dx.execute()                 | 158 |
| 10.2.36 | dx.map()                     | 158 |
| 10.2.37 | eliminate()                  | 159 |
| 10.2.38 | fix()                        | 161 |
| 10.2.39 | frame_order.cone_pdb()       | 162 |
| 10.2.40 | frame_order.domain_to_pdb()  | 162 |
| 10.2.41 | frame_order.pivot()          | 163 |
| 10.2.42 | frame_order.ref_domain()     | 163 |
| 10.2.43 | frame_order.select_model()   | 163 |
| 10.2.44 | freq.set()                   | 164 |
| 10.2.45 | grace.view()                 | 164 |
| 10.2.46 | grace.write()                | 165 |
| 10.2.47 | grid_search()                | 166 |
| 10.2.48 | intro_off()                  | 168 |
| 10.2.49 | intro_on()                   | 168 |
| 10.2.50 | jw_mapping.set_freq()        | 168 |
| 10.2.51 | minimise()                   | 169 |
| 10.2.52 | model_free.create_model()    | 172 |
| 10.2.53 | model_free.delete()          | 174 |
| 10.2.54 | model_free.remove_tm()       | 174 |
| 10.2.55 | model_free.select_model()    | 174 |
| 10.2.56 | model_selection()            | 176 |
| 10.2.57 | molecule.copy()              | 177 |
| 10.2.58 | molecule.create()            | 177 |
| 10.2.59 | molecule.delete()            | 178 |
| 10.2.60 | molecule.display()           | 178 |
| 10.2.61 | molecule.name()              | 178 |
| 10.2.62 | molecule.type()              | 179 |
| 10.2.63 | molmol.clear_history()       | 180 |
| 10.2.64 | molmol.command()             | 180 |
| 10.2.65 | molmol.macro_apply()         | 180 |
| 10.2.66 | molmol.macro_run()           | 181 |
| 10.2.67 | molmol.macro_write()         | 181 |
| 10.2.68 | molmol.ribbon()              | 197 |
| 10.2.69 | molmol.tensor_pdb()          | 197 |
| 10.2.70 | molmol.view()                | 198 |
| 10.2.71 | monte_carlo.create_data()    | 198 |
| 10.2.72 | monte_carlo.error_analysis() | 199 |
| 10.2.73 | monte_carlo.initial_values() | 200 |
| 10.2.74 | monte_carlo.off()            | 201 |
| 10.2.75 | monte_carlo.on()             | 202 |

|          |                                               |     |
|----------|-----------------------------------------------|-----|
| 10.2.76  | <code>monte_carlo.setup()</code>              | 202 |
| 10.2.77  | <code>n_state_model.CoM()</code>              | 203 |
| 10.2.78  | <code>n_state_model.cone_pdb()</code>         | 204 |
| 10.2.79  | <code>n_state_model.elim_no_prob()</code>     | 204 |
| 10.2.80  | <code>n_state_model.number_of_states()</code> | 205 |
| 10.2.81  | <code>n_state_model.ref_domain()</code>       | 205 |
| 10.2.82  | <code>n_state_model.select_model()</code>     | 205 |
| 10.2.83  | <code>noe.read_restraints()</code>            | 206 |
| 10.2.84  | <code>noe.spectrum_type()</code>              | 206 |
| 10.2.85  | <code>palmer.create()</code>                  | 207 |
| 10.2.86  | <code>palmer.execute()</code>                 | 207 |
| 10.2.87  | <code>palmer.extract()</code>                 | 208 |
| 10.2.88  | <code>paramag.centre()</code>                 | 208 |
| 10.2.89  | <code>pcs.back_calc()</code>                  | 208 |
| 10.2.90  | <code>pcs.calc_q_factors()</code>             | 209 |
| 10.2.91  | <code>pcs.copy()</code>                       | 209 |
| 10.2.92  | <code>pcs.corr_plot()</code>                  | 209 |
| 10.2.93  | <code>pcs.delete()</code>                     | 210 |
| 10.2.94  | <code>pcs.display()</code>                    | 210 |
| 10.2.95  | <code>pcs.read()</code>                       | 210 |
| 10.2.96  | <code>pcs.weight()</code>                     | 211 |
| 10.2.97  | <code>pcs.write()</code>                      | 211 |
| 10.2.98  | <code>pdc.read()</code>                       | 211 |
| 10.2.99  | <code>pipe.copy()</code>                      | 212 |
| 10.2.100 | <code>pipe.create()</code>                    | 212 |
| 10.2.101 | <code>pipe.current()</code>                   | 212 |
| 10.2.102 | <code>pipe.delete()</code>                    | 213 |
| 10.2.103 | <code>pipe.display()</code>                   | 213 |
| 10.2.104 | <code>pipe.hybridise()</code>                 | 213 |
| 10.2.105 | <code>pipe.switch()</code>                    | 213 |
| 10.2.106 | <code>pymol.cartoon()</code>                  | 214 |
| 10.2.107 | <code>pymol.clear_history()</code>            | 214 |
| 10.2.108 | <code>pymol.command()</code>                  | 214 |
| 10.2.109 | <code>pymol.cone_pdb()</code>                 | 214 |
| 10.2.110 | <code>pymol.macro_apply()</code>              | 215 |
| 10.2.111 | <code>pymol.macro_run()</code>                | 218 |
| 10.2.112 | <code>pymol.macro_write()</code>              | 218 |
| 10.2.113 | <code>pymol.tensor_pdb()</code>               | 223 |
| 10.2.114 | <code>pymol.vector_dist()</code>              | 223 |
| 10.2.115 | <code>pymol.view()</code>                     | 225 |
| 10.2.116 | <code>rdc.back_calc()</code>                  | 225 |
| 10.2.117 | <code>rdc.calc_q_factors()</code>             | 225 |
| 10.2.118 | <code>rdc.copy()</code>                       | 225 |
| 10.2.119 | <code>rdc.corr_plot()</code>                  | 226 |
| 10.2.120 | <code>rdc.delete()</code>                     | 226 |
| 10.2.121 | <code>rdc.display()</code>                    | 226 |
| 10.2.122 | <code>rdc.read()</code>                       | 227 |
| 10.2.123 | <code>rdc.weight()</code>                     | 227 |
| 10.2.124 | <code>rdc.write()</code>                      | 228 |



|          |                                                 |     |
|----------|-------------------------------------------------|-----|
| 10.2.125 | <code>relax_data.back_calc()</code>             | 228 |
| 10.2.126 | <code>relax_data.copy()</code>                  | 228 |
| 10.2.127 | <code>relax_data.delete()</code>                | 229 |
| 10.2.128 | <code>relax_data.display()</code>               | 229 |
| 10.2.129 | <code>relax_data.peak_intensity_type()</code>   | 229 |
| 10.2.130 | <code>relax_data.read()</code>                  | 230 |
| 10.2.131 | <code>relax_data.temp_calibration()</code>      | 230 |
| 10.2.132 | <code>relax_data.temp_control()</code>          | 231 |
| 10.2.133 | <code>relax_data.write()</code>                 | 231 |
| 10.2.134 | <code>relax_fit.relax_time()</code>             | 231 |
| 10.2.135 | <code>relax_fit.select_model()</code>           | 232 |
| 10.2.136 | <code>reset()</code>                            | 232 |
| 10.2.137 | <code>residue.copy()</code>                     | 232 |
| 10.2.138 | <code>residue.create()</code>                   | 233 |
| 10.2.139 | <code>residue.delete()</code>                   | 233 |
| 10.2.140 | <code>residue.display()</code>                  | 233 |
| 10.2.141 | <code>residue.name()</code>                     | 234 |
| 10.2.142 | <code>residue.number()</code>                   | 234 |
| 10.2.143 | <code>results.display()</code>                  | 235 |
| 10.2.144 | <code>results.read()</code>                     | 235 |
| 10.2.145 | <code>results.write()</code>                    | 235 |
| 10.2.146 | <code>select.all()</code>                       | 236 |
| 10.2.147 | <code>select.read()</code>                      | 236 |
| 10.2.148 | <code>select.reverse()</code>                   | 237 |
| 10.2.149 | <code>select.spin()</code>                      | 237 |
| 10.2.150 | <code>sequence.copy()</code>                    | 238 |
| 10.2.151 | <code>sequence.display()</code>                 | 238 |
| 10.2.152 | <code>sequence.read()</code>                    | 239 |
| 10.2.153 | <code>sequence.write()</code>                   | 240 |
| 10.2.154 | <code>spectrum.baseplane_rmsd()</code>          | 240 |
| 10.2.155 | <code>spectrum.delete()</code>                  | 241 |
| 10.2.156 | <code>spectrum.error_analysis()</code>          | 241 |
| 10.2.157 | <code>spectrum.integration_points()</code>      | 243 |
| 10.2.158 | <code>spectrum.read_intensities()</code>        | 243 |
| 10.2.159 | <code>spectrum.replicated()</code>              | 244 |
| 10.2.160 | <code>spin.copy()</code>                        | 245 |
| 10.2.161 | <code>spin.create()</code>                      | 245 |
| 10.2.162 | <code>spin.create_pseudo()</code>               | 245 |
| 10.2.163 | <code>spin.delete()</code>                      | 246 |
| 10.2.164 | <code>spin.display()</code>                     | 246 |
| 10.2.165 | <code>spin.element()</code>                     | 247 |
| 10.2.166 | <code>spin.name()</code>                        | 247 |
| 10.2.167 | <code>spin.number()</code>                      | 248 |
| 10.2.168 | <code>state.load()</code>                       | 249 |
| 10.2.169 | <code>state.save()</code>                       | 249 |
| 10.2.170 | <code>structure.add_atom()</code>               | 250 |
| 10.2.171 | <code>structure.connect_atom()</code>           | 250 |
| 10.2.172 | <code>structure.create_diff_tensor_pdb()</code> | 250 |
| 10.2.173 | <code>structure.create_vector_dist()</code>     | 251 |

|           |                                                                |            |
|-----------|----------------------------------------------------------------|------------|
| 10.2.174  | <code>structure.delete()</code>                                | 252        |
| 10.2.175  | <code>structure.displacement()</code>                          | 252        |
| 10.2.176  | <code>structure.get_pos()</code>                               | 253        |
| 10.2.177  | <code>structure.load_spins()</code>                            | 253        |
| 10.2.178  | <code>structure.read_pdb()</code>                              | 254        |
| 10.2.179  | <code>structure.read_xyz()</code>                              | 255        |
| 10.2.180  | <code>structure.rotate()</code>                                | 256        |
| 10.2.181  | <code>structure.superimpose()</code>                           | 256        |
| 10.2.182  | <code>structure.translate()</code>                             | 256        |
| 10.2.183  | <code>structure.vectors()</code>                               | 257        |
| 10.2.184  | <code>structure.write_pdb()</code>                             | 258        |
| 10.2.185  | <code>sys_info()</code>                                        | 258        |
| 10.2.186  | <code>system()</code>                                          | 258        |
| 10.2.187  | <code>temperature()</code>                                     | 259        |
| 10.2.188  | <code>value.copy()</code>                                      | 259        |
| 10.2.189  | <code>value.display()</code>                                   | 260        |
| 10.2.190  | <code>value.read()</code>                                      | 262        |
| 10.2.191  | <code>value.set()</code>                                       | 268        |
| 10.2.192  | <code>value.write()</code>                                     | 274        |
| 10.2.193  | <code>vmd.view()</code>                                        | 276        |
| <b>11</b> | <b>Licence</b>                                                 | <b>279</b> |
| 11.1      | Copying, modification, sublicencing, and distribution of relax | 279        |
| 11.2      | The GPL                                                        | 279        |

## List of Figures

|     |                                                                            |     |
|-----|----------------------------------------------------------------------------|-----|
| 1.1 | Prompt screenshot                                                          | 5   |
| 1.2 | Scripting screenshot                                                       | 9   |
| 1.3 | GUI screenshot                                                             | 10  |
| 4.1 | NOE plot                                                                   | 25  |
| 6.1 | A schematic of the model-free optimisation protocol of Mandel et al., 1995 | 53  |
| 6.2 | Model-free analysis using the diffusion seeded paradigm                    | 54  |
| 6.3 | A schematic of the new model-free optimisation protocol                    | 56  |
| 8.1 | The construction of the model-free gradient.                               | 63  |
| 8.2 | The model-free Hessian kite.                                               | 65  |
| 8.3 | $\chi^2$ dependencies of the values, gradients, and Hessians.              | 66  |
| 9.1 | The core design of relax.                                                  | 135 |

# Abbreviations

**AIC** Akaike's Information Criteria

**AICc** small sample size corrected AIC

**BIC** Bayesian Information Criteria

$C(\tau)$  correlation function

$\chi^2$  chi-squared function

**CSA** chemical shift anisotropy

$\mathfrak{D}$  the set of diffusion tensor parameters

$\mathfrak{D}_{\parallel}$  the eigenvalue of the spheroid diffusion tensor corresponding to the unique axis of the tensor

$\mathfrak{D}_{\perp}$  the eigenvalue of the spheroid diffusion tensor corresponding to the two axes perpendicular to the unique axis

$\mathfrak{D}_a$  the anisotropic component of the Brownian rotational diffusion tensor

$\mathfrak{D}_{iso}$  the isotropic component of the Brownian rotational diffusion tensor

$\mathfrak{D}_r$  the rhombic component of the Brownian rotational diffusion tensor

$\mathfrak{D}_{ratio}$  the ratio of  $\mathfrak{D}_{\parallel}$  to  $\mathfrak{D}_{\perp}$

$\mathfrak{D}_x$  the eigenvalue of the Brownian rotational diffusion tensor in which the corresponding eigenvector defines the x-axis of the tensor

$\mathfrak{D}_y$  the eigenvalue of the Brownian rotational diffusion tensor in which the corresponding eigenvector defines the y-axis of the tensor

$\mathfrak{D}_z$  the eigenvalue of the Brownian rotational diffusion tensor in which the corresponding eigenvector defines the z-axis of the tensor

$\epsilon_i$  elimination value

$J(\omega)$  spectral density function

**NOE** nuclear Overhauser effect

**pdf** probability distribution function

$r$  bond length

$R_1$  spin-lattice relaxation rate

$R_2$  spin-spin relaxation rate

$R_{ex}$  chemical exchange relaxation rate

$S^2$ ,  $S_f^2$ , **and**  $S_s^2$  model-free generalised order parameters

$\tau_e$ ,  $\tau_f$ , **and**  $\tau_s$  model-free effective internal correlation times

$\tau_m$  global rotational correlation time

# Chapter 1

## Introduction

The program relax is designed for the study of the dynamics of proteins or other macromolecules through the analysis of NMR relaxation data. It is a community driven project created by NMR spectroscopists for NMR spectroscopists. It supports exponential curve fitting for the calculation of the  $R_1$  and  $R_2$  relaxation rates, calculation of the NOE, reduced spectral density mapping, and the Lipari and Szabo model-free analysis.

The aim of relax is to provide a seamless and extremely flexible environment able to accept input in any format produced by other NMR software, able to faultlessly create input files, control, and read output from various programs including Modelfree and Dasha, output results in many formats, and visualise the data by controlling programs such as Grace, OpenDX, MOLMOL, and PyMOL. All data analysis tools from optimisation to model selection to Monte Carlo simulations are inbuilt into relax. Therefore the use of additional programs is optional.

The flexibility of relax arises from the choice of either relax's scripting capabilities or its Python prompt interface. Extremely complex scripts can be created from simple building blocks to fully automate data analysis. A number of sample scripts have been provided to help understand script construction. In addition, any of Python's powerful features or functions can be incorporated as the script is executed as an arbitrary Python source file within relax's environment. The modules of relax can also be used as a vast library of dynamics related functions by your own software.

relax is free software (free as in freedom) which is licenced under the GNU General Public Licence (GPL). You are free to copy, modify, or redistribute relax under the terms of the GPL.

### 1.1 Program features

#### 1.1.1 Literature

The primary references for the program relax are [d'Auvergne and Gooley \(2008a\)](#) and [d'Auvergne and Gooley \(2008b\)](#).

Other literature related to the improved model-free analysis used within relax, which can nevertheless be applied to other techniques such as SRLS, include model-free model selection (d’Auvergne and Gooley, 2003; Chen et al., 2004), model-free model elimination (d’Auvergne and Gooley, 2006), the theory (d’Auvergne and Gooley, 2007) behind the new model-free optimisation protocol (d’Auvergne and Gooley, 2008b), and the hybridisation of different models (Horne et al., 2007; d’Auvergne and Gooley, 2008b). Most of these details can be found in the PhD thesis of d’Auvergne (2006).

### 1.1.2 Supported NMR theories

The following relaxation data analysis techniques are currently supported by relax:

- Model-free analysis (Lipari and Szabo, 1982a,b; Clore et al., 1990).
- Reduced spectral density mapping (Farrow et al., 1995; Lefevre et al., 1996).
- Exponential curve fitting (to find the  $R_1$  and  $R_2$  relaxation rates).
- Steady-state NOE calculation.

### The future

At some time in the future the following techniques are planned to be implemented within relax:

- Relaxation dispersion.
- SRLS – Slowly relaxing local structure (Tugarinov et al., 2001).

Because relax is free software, if you would like to contribute addition features, functions, or modules which you have written for your own publications for the benefit of the field, almost anything relating to molecular dynamics may be accepted. Please see the Open Source chapter for more details.

### 1.1.3 Data analysis tools

The following tools are implemented as modular components to be used by any data analysis technique:

- Numerous high-precision optimisation algorithms.
- Model selection (d’Auvergne and Gooley, 2003; Chen et al., 2004):
  - Akaike’s Information Criteria (AIC).
  - Small sample size corrected AIC (AICc).
  - Bayesian or Schwarz Information Criteria (BIC).

- Bootstrap model selection.
- Single-item-out cross-validation (CV).
- Hypothesis testing ANOVA model selection (only the model-free specific technique of [Mandel et al. \(1995\)](#) is supported).
- Monte Carlo simulations (error analysis for all data analysis techniques).
- Model elimination – the removal of failed models prior to model selection ([d’Auvergne and Gooley, 2006](#)).

#### 1.1.4 Data visualisation

The results of an analysis, or any data input into relax, can be visualised using a number of programs:

**MOLMOL** 1D data can be mapped onto a structure either by the creation of MOLMOL macros or by direct control of the program.

**PyMOL** 3D objects such as the diffusion tensor representation can be displayed with the structure.

**Grace** any 2D data can be plotted.

**OpenDX** The chi-squared space of models with three parameters can be mapped and 3D images of the space produced.

#### 1.1.5 Interfacing with other programs

relax can create the input files, execute in-line, and then read the output of the following programs. These programs can be used as optimisation engines replacing the minimisation algorithms built into relax:

- Dasha (model-free analysis).
- Modelfree (model-free analysis).

#### 1.1.6 The user interfaces (UI)

relax can be used through the following UIs:

**The prompt** this is the primary interface of relax. Rather than reinventing a new command language, relax’s interface is the powerful Python prompt. This gives the power user full access to a proven programming language. See [Figure 1.1](#) for a screenshot.

**Scripting** this provides a more powerful and flexible framework for controlling the program. The script will be executed as Python code enabling advanced programming for automating data analysis. All the features available within the prompt environment are accessible to the script. See Figure 1.2 for a screenshot.

**GUI** the graphical user interface provides a sub-set of relax's features - the automatic  $R_1$  and  $R_2$  relaxation rate curve-fitting, the NOE calculations, and the automatic model-free analysis provided by the `dauvergne_protocol` module (d'Auvergne and Gooley, 2008b). See Figure 1.3 for a screenshot.

## 1.2 How to use relax

### 1.2.1 The prompt

The primary interface of relax is the prompt. After typing 'relax' within a terminal you will be presented with

```
relax>
```

This is the Python prompt which has been tailored specifically for relax. You will hence have full access, if desired, to the power of the Python programming language to manipulate your data. You can for instance type

```
relax> print "Hello World"
```

the result being

```
relax> print "Hello World"
Hello World
relax>
```

Or using relax as a calculator

```
relax> (1.0 + (2 * 3))/10
0.69999999999999996
relax>
```

### 1.2.2 Python

relax has been designed such that knowledge about Python is not required to be able to fully use the program. A few basics though will aid in understanding relax.

A number of simple programming axioms includes that of strings, integers, floating point numbers, and lists. A string is text and within Python (as well as relax) this is delimited by either single or double quotes. An integer is a number with no decimal point whereas a float is a number with a decimal point. A list in Python (called an array in other languages) is a list of anything separated by commas and delimited by square brackets, an example is `[0, 1, 2, 'a', 1.2143235]`.

Probably the most important detail is that functions in Python require brackets around their arguments. For example



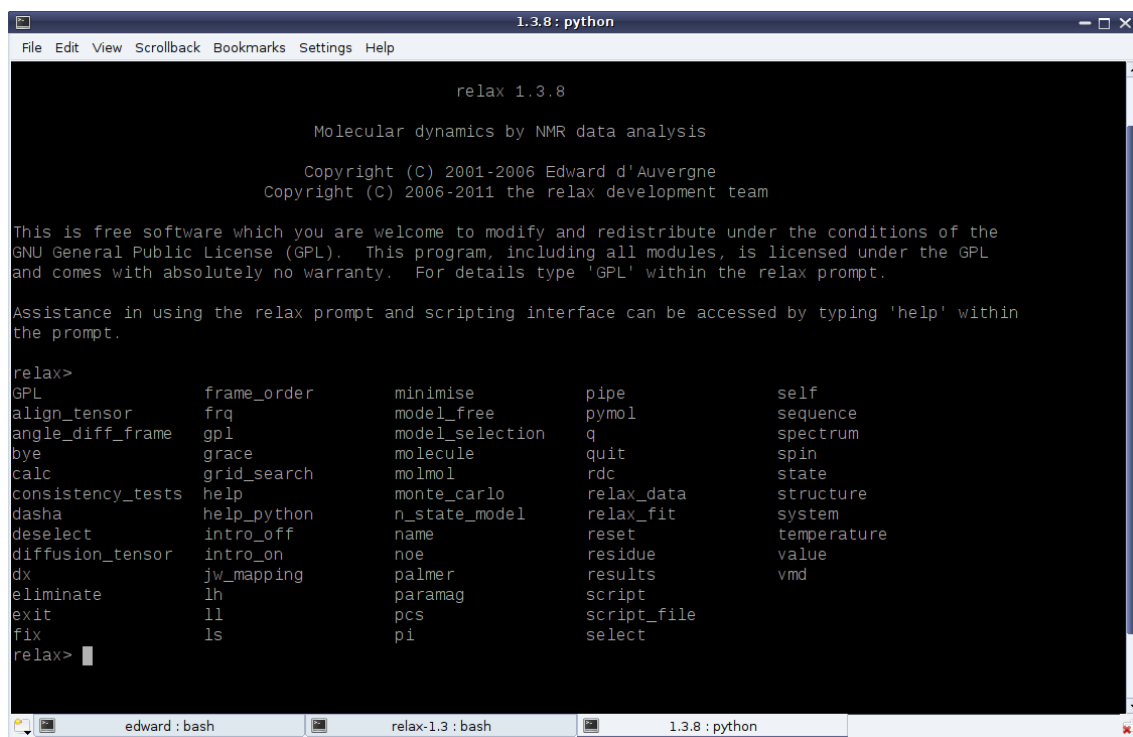


Figure 1.1: A screenshot of relax being run in the primary prompt mode.

```
relax> minimise()
```

will commence minimisation however

```
relax> minimise
```

will do nothing.

The arguments to a function are simply a comma separated list within the brackets of the function. For example to save the program's current state type

```
relax> state.save('save', force=True)
```

Two types of arguments exist in Python – standard arguments and keyword arguments. The majority of arguments you will encounter within relax are keyword arguments however you may, in rare cases, encounter a non-keyword argument. For these standard arguments just type the values in, although they must be in the correct order. Keyword arguments consist of two parts – the key and the value. For example the key may be `file` and the value you would like to supply is `'R1.out'`. Various methods exist for supplying this argument. Firstly you could simply type `'R1.out'` into the correct position in the argument list. Secondly you can type `file='R1.out'`. The power of this second option is that argument order is unimportant. Therefore if you would like to change the default value of the very last argument, you don't have to supply values for all other arguments. The only catch is that standard arguments must come before the keyword arguments.

### 1.2.3 User functions

For standard data analysis a large number of specially tailored functions called ‘user functions’ have been implemented. These are accessible from the relax prompt by simply typing the name of the function. An example is ‘`help()`’. An alphabetical listing of all accessible user functions together with full descriptions is presented later in this manual.

A few special objects which are available within the prompt are not actually functions. These objects do not require brackets at their end for them to function. For example to exit relax type

```
relax> exit
```

Another special object is that of the function class. This object is simply a container which holds a number of user functions. You can access the user function within the class by typing the name of the class, then a dot ‘.’, followed by the name of the user function. An example is the user function for reading relaxation data out of a file and loading the data into relax. The function is called ‘`read`’ and the class is called ‘`relax_data`’. To execute the function, type something like

```
relax> relax_data.read('R1', '600', 600.0 * 1e6, 'r1.600.out')
```

On first usage the relax prompt can be quite daunting. Two features exist to increase the usability of the prompt – the help system and tab completion.

### 1.2.4 The help system

For assistance in using a function simply type

```
help(function)
```

In addition to functions if

```
help(object)
```

is typed the help for the python object is returned. This system is similar to the help function built into the python interpreter, which has been renamed to `help_python`, with the interactive component removed. For the standard interactive python help system type

```
help_python()
```

### 1.2.5 Tab completion

Tab completion is implemented to prevent insanity as the function names can be quite long – a deliberate feature to improve usability. The behaviour of the tab completion is very similar to that of the bash prompt.

Not only is tab completion useful for preventing RSI but it can also be used for listing all available functions. To begin with if you hit the [TAB] key without typing any text all available functions will be listed (along with function classes and other python objects). This extends to the exploration of user functions within a function class. For example to list the user functions within the function class ‘`model_free`’ type

```
relax> model_free.
```

The dot character at the end is essential. After hitting the [TAB] key you should see something like

```
relax> model_free.
model_free.__class__
model_free.__doc__
model_free.__init__
model_free.__module__
model_free.__relax__
model_free.__relax_help__
model_free.create_model
model_free.delete
model_free.remove_tm
model_free.select_model
relax> model_free.
```

All the objects beginning with an underscore are “hidden”, they contain information about the function class and should be ignored. From the listing the user functions ‘copy’, ‘create\_model’, ‘delete’, ‘remove\_tm’, and ‘select\_model’ contained within ‘model\_free’ are all visible.

### 1.2.6 The data pipe

Within relax all user functions operate on data stored within the current data pipe. This pipe stores data is input, processed, or output as user functions are called. There are different types of data pipe for different analyses, e.g. a reduced spectral density mapping pipe, a model-free pipe, an exponential curve-fitting pipe, etc. Multiple data pipes can be created within relax and various operations performed in sequence on these pipes. This is useful for operations such as model selection whereby the function ‘model\_selection’ can operate on a number of pipes corresponding to different models and then assign the results to a newly created pipe. When running relax you choose which pipe you are currently in by using the ‘pipe.switch’ user function to jump between pipes.

The flow of data through relax can be thought of as travelling through these pipes. User functions exist to transfer data between these pipes and other functions combine data from multiple pipes into one or vice versa. The simplest invocation of relax would be the creation of a single data pipe and with the data being processed as it is passing through this pipe.

The primary method for creating a data pipe is through the user function ‘pipe.create’. For example

```
relax> pipe.create('m1', 'mf')
```

will create a model-free data pipe labelled ‘m1’. The following is a table of all the types which can be assigned to a data pipe.

| Data pipe type | Description                      |
|----------------|----------------------------------|
| 'jw'           | Reduced spectral density mapping |
| 'mf'           | Model-free data analysis         |
| 'N-state'      | N-state model of domain motions  |
| 'noe'          | Steady state NOE calculation     |
| 'relax_fit'    | Relaxation curve-fitting         |
| 'srls'         | SRLS analysis                    |

Currently the NOE calculation, relaxation curve-fitting, model-free analysis, and reduced spectral density mapping features of relax are implemented (if this documentation is out of date then you may be able to do a lot more).

### 1.2.7 Scripting

What ever is done within the prompt is also accessible through scripting (Figure 1.2). Just type your commands into a text file and then at the terminal type

```
$ relax your_script
```

An example of a simple script which will minimise the model-free model 'm4' after loading six relaxation data sets is

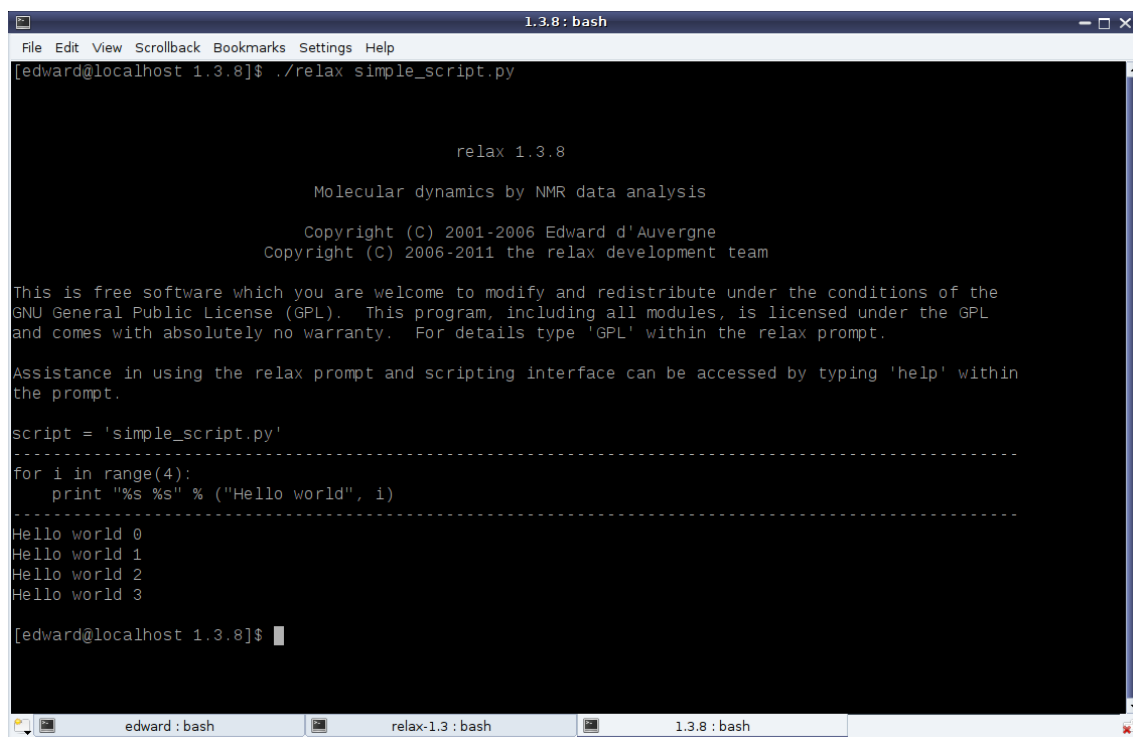
```
# Create the data pipe.
name = 'm4'
pipe.create(name, 'mf')

# Nuclei type
nuclei('N')

# Load the sequence.
sequence.read('noe.500.out')

# Load the relaxation data.
relax_data.read('R1', '600', 600.0 * 1e6, 'r1.600.out')
relax_data.read('R2', '600', 600.0 * 1e6, 'r2.600.out')
relax_data.read('NOE', '600', 600.0 * 1e6, 'noe.600.out')
relax_data.read('R1', '500', 500.0 * 1e6, 'r1.500.out')
relax_data.read('R2', '500', 500.0 * 1e6, 'r2.500.out')
relax_data.read('NOE', '500', 500.0 * 1e6, 'noe.500.out')

# Setup other values.
diffusion_tensor.init((2e-8, 1.3, 60, 290), param-types=1, axial_type='prolate',
fixed=True)
value.set(1.02 * 1e-10, 'bond_length')
value.set(-160 * 1e-6, 'csa')
value.set('15N', 'heteronucleus')
value.set('1H', 'proton')
```



```
1.3.8: bash
File Edit View Scrollback Bookmarks Settings Help
[edward@localhost 1.3.8]$ ./relax simple_script.py

relax 1.3.8

Molecular dynamics by NMR data analysis

Copyright (C) 2001-2006 Edward d'Auvergne
Copyright (C) 2006-2011 the relax development team

This is free software which you are welcome to modify and redistribute under the conditions of the
GNU General Public License (GPL). This program, including all modules, is licensed under the GPL
and comes with absolutely no warranty. For details type 'GPL' within the relax prompt.

Assistance in using the relax prompt and scripting interface can be accessed by typing 'help' within
the prompt.

script = 'simple_script.py'
-----
for i in range(4):
    print "%s %s" % ("Hello world", i)
-----
Hello world 0
Hello world 1
Hello world 2
Hello world 3

[edward@localhost 1.3.8]$
```

Figure 1.2: A screenshot of relax being run in scripting mode.

```
# Select a preset model-free model.
model_free.select_model(model=name)

# Grid search.
grid_search(inc=11)

# Minimise.
minimise('newton')

# Finish.
results.write(file='results', force=True)
state.save('save', force=True)
```

Scripting is much more powerful than the prompt as advanced Python programming can be employed (see the file 'full\_analysis.py' in the 'sample\_scripts' directory for an example).

### 1.2.8 Sample scripts

A few sample scripts have been provided in the directory 'sample\_scripts'. These can be copied and modified for different types of data analysis.

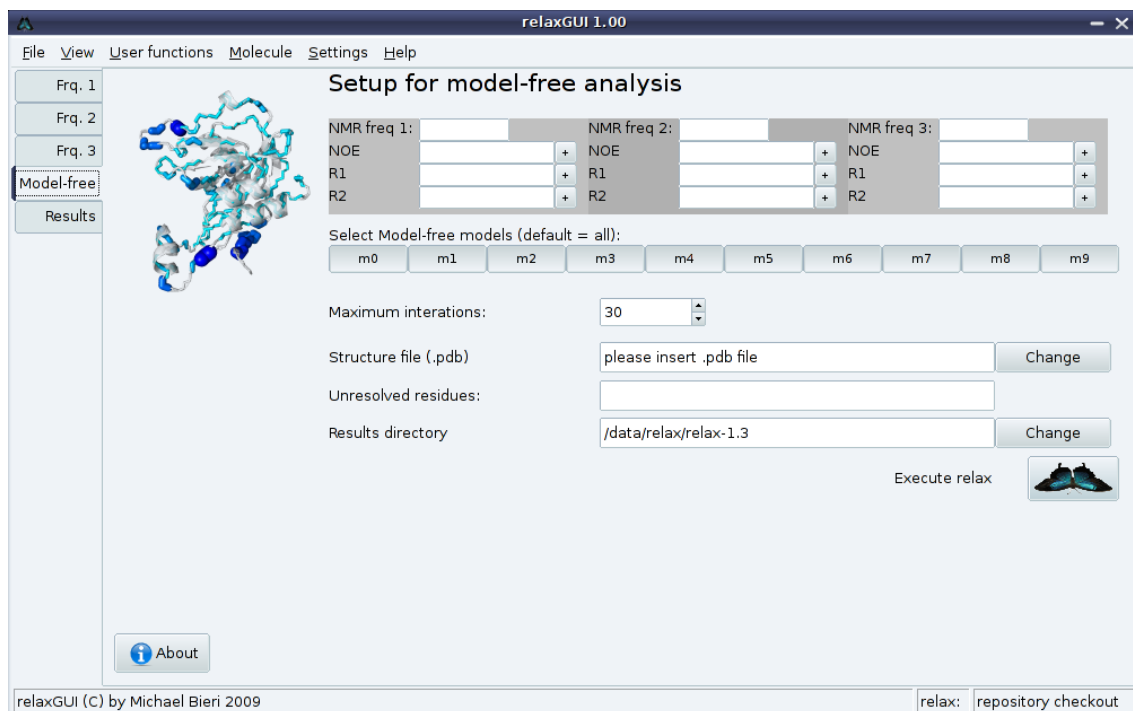


Figure 1.3: A screenshot of relax being run in GUI mode.

### 1.2.9 The test suite

To test that the program functions correctly, relax possesses an inbuilt test suite. The suite is a collection of simple tests which execute or probe different parts of the program checking that the software runs without problem. The test suite is executed by running relax using the command `'relax --test-suite'`.

### 1.2.10 The GUI

If the wx Python module is installed on your system, you will have access to the GUI interface of relax. To launch relax in GUI mode, type either

```
$ relax -g
```

or

```
$ relax --gui
```

The GUI is still in development, so many of the features of the prompt/scripting user interfaces are not available (however the prompt and script modes can be accessed through the menus if needed). Currently the GUI is an interface to the automatic analyses which some of the sample scripts utilise. This provides an easy way for the user to perform quick analyses. The interface is broken into a number of sections via tabs. One tab provides access to the steady-state NOE calculation with pseudo Monte Carlo simulations for error analysis (this falls back to bootstrapping as this is a calculation rather than optimisation). Another two tabs provide easy access to optimisations and error analysis for the  $R_1$  and  $R_2$  relaxation rates. A fully automatic model-free protocol is provided in another

tab. This operates via the `dauvergne_protocol` module which implements the protocol of [d'Auvergne and Gooley \(2008b\)](#). A final tab provides visual access to the results including Grace visualisations, PyMOL macros, and a table of the model-free results.

### 1.2.11 Access to the internals of relax

To enable advanced Python scripting and control many parts of relax have been designed in an object oriented fashion. If you would like to play with internals of the program the entirety of relax is accessible by importation. For example all data is contained within the object called the relax data store which, to be able to access it, needs be imported by typing:

```
relax> from data import Data as relax_data_store
```

This is a dictionary type object which contains the multiple data pipes. All of relax's packages, modules, functions, and classes are also accessible by import statements. For example to create a rotation matrix from three Euler angles in the z-y-z notation, type:

```
relax> alpha = 0.1342
relax> beta = 1.0134
relax> gamma = 2.4747
relax> from maths_fns.rotation_matrix import R_euler_zyz
relax> from numpy import float64, zeros
relax> R = zeros((3,3), float64)
relax> R_euler_zyz(R, alpha, beta, gamma)
relax> R
```

## 1.3 Usage of the name relax

The program relax is so relaxed that the first letter should always be in lower case!





## Chapter 2

# Installation instructions

### 2.1 Dependencies

The following packages need to be installed before using relax:

**Python:** Version 2.5 or higher.

**NumPy:** Version 1.0.4 or higher. This package is used for most of the numerical calculations within relax.

**SciPy:** Version 0.7.1 or higher. This package is also optional. It is required only for the frame order theory analyses.

**wxPython:** Version 2.8 or higher. This package is optional. It is required for the operation of the graphical user interface (GUI).

Older versions of these packages may work, use them at your own risk. If, for older dependency versions, errors do occur please submit a bug report to the bug tracker at <https://gna.org/bugs/?group=relax>. That way a solution may be created for the next relax release.

### 2.2 Installation

#### 2.2.1 The precompiled versus source distribution

Two types of software packages are available for download – the precompiled and source distribution. Currently only relaxation curve-fitting requires compilation to function and all other features of relax will be fully functional without compilation. If relaxation curve-fitting is required but no precompiled version of relax exists for your operating system or architecture then, if a C compiler is present, the C code can be compiled into the shared objects files \*.so which are loaded as modules into relax. To build these modules the Sconstruct system from <http://scons.org/> is required. This software only depends on Python which is essential for running relax anyway. Once Sconstruct is installed type

```
$ scons
```

in the base directory where relax has been installed and the C modules should, hopefully, compile without any problems. Otherwise please submit a bug report to the bug tracker at <https://gna.org/bugs/?group=relax>.

### 2.2.2 Installation on GNU/Linux

To install the program relax on a GNU/Linux system download either the precompiled distribution labelled `relax-x.x.x.GNU-Linux.arch.tar.bz2` matching your machine architecture or the source distribution `relax-x.x.x.src.tar.bz2`. A number of installation methods are possible. The simplest way is to switch to the user ‘root’, unpack and decompress the archive within the `/usr/local` directory by typing, for instance

```
$ tar jxvf relax-x.x.x.GNU-Linux.i686.tar.bz2
```

then create a symbolic link in `/usr/local/bin` by moving to that directory and typing

```
$ ln -s ../relax/relax .
```

and finally running relax to create the byte-compiled Python `*.pyc` files to speed up the start time of relax by typing

```
$ relax --test
```

Alternatively if the Sconstruct system is installed typing

```
$ scons install
```

in the relax base directory will create a directory in `/usr/local/` called `relax`, copy all the uncompressed and untarred files into this directory, create a symbolic link in `/usr/local/bin` to the file `/usr/local/relax/relax`, and then finally run relax to create the byte-compiled Python `*.pyc`. To change the installation path to a non-standard location the Sconstruct script `sconstruct` in the base relax directory should be modified by changing the variable `INSTALL_PATH` to point to the desired location.

### 2.2.3 Installation on MS Windows

In addition to the above dependencies, running relax on MS Windows requires a number of additional programs. These include:

**pyreadline:** Version 1.3 or higher ([download](#)).

**ctypes:** The pyreadline package requires ctypes ([download](#)).

To install, simply download the pre-compiled binary distribution `relax-x.x.x.Win32.zip` or the source distribution `relax-x.x.x.src.zip` and extract the files to `C:\Program Files\relax-x.x.x`. Then add this directory to the system environment path (in Windows XP, right click on ‘My Computer’, go to ‘Properties’, click on the ‘Advanced’ tab, and click on the ‘Environment Variables’ button. Then double click on the ‘Path’ system variable and add the text “;C:\Program Files\relax-x.x.x” to the end of variable value field.

The Python installation must also be located on the path (add the text “;C:\Program Files\Python24”, changing the text to point to the correct directory, to the field). To run the program from any directory inside the Windows command prompt (or dos prompt) type:

```
C:\> relax
```

### 2.2.4 Installation on Mac OS X

Please write me if you know how to do this!

### 2.2.5 Installation on your OS

Please write me if you know how to do this!

### 2.2.6 Running a non-compiled version

Compilation of the C code is not essential for running relax, however certain features of the program will be disabled. Currently only the exponential curve-fitting for determining the  $R_1$  and  $R_2$  relaxation rates requires compilation. To run relax without compilation install the dependencies detailed above, download the source distribution which should be named `relax-x.x.x.src.tar.bz2`, extract the files, and then run the file called `relax` in the base directory.

## 2.3 Optional programs

The following is a list of programs which can be used by relax although they are not essential for normal use.

### 2.3.1 Grace

Grace is a program for plotting two dimensional data sets in a professional looking manner. It is used to visualise parameter values. It can be downloaded from <http://plasma-gate.weizmann.ac.il/Grace/>.

### 2.3.2 OpenDX

Version 4.1.3 or compatible. OpenDX is used for viewing the output of the space mapping function and is executed by passing the command `dx` to the command line with various options. The program is designed for visualising multidimensional data and can be found at <http://www.opendx.org/>.

### 2.3.3 Molmol

Molmol is used for viewing the PDB structures loaded into the program and to display parameter values mapped onto the structure.

### 2.3.4 PyMOL

PDB structures can also be viewed using PyMOL. Although the mapping of parameter values onto the structure is not yet supported, this program can be used to display geometric objects generated by relax for representing physical concepts such as the diffusion tensor.

### 2.3.5 Dasha

Dasha is a program used for model-free analysis of NMR relaxation data. It can be used as an optimisation engine to replace the minimisation algorithms implemented within relax.

### 2.3.6 Modelfree4

Art Palmer's Modelfree4 program is also designed for model-free analysis and can be used as an optimisation engine to replace relax's high precision minimisation algorithms.

## Chapter 3

# Open source infrastructure

### 3.1 The relax web sites

The main web site for relax is <http://nmr-relax.com>. From these pages general information about the program, links to the latest documentation, links to the most current software releases, and information about the mailing lists are available. There are also Google search capabilities built into the pages for searching both the HTML version of the manual and the archives of the mailing lists.

The relax web site is hosted by the Gna! project (<https://gna.org/>) which is described as “a central point for development, distribution and maintenance of Libre Software (Free Software) projects”. relax is a registered Gna! project and its primary Gna! web site is <https://gna.org/projects/relax>. This site contains many more technical details than the main web site.

### 3.2 The mailing lists

A number of mailing lists have been created covering different aspects of relax. These include the announcement list, the relax users list, the relax development list, and the relax committers list.

#### 3.2.1 relax-announce

The relax announcement list “relax-announce at gna.org” is reserved for important announcements about the program including the release of new program versions. The amount of traffic on this list is relatively low. If you would like to receive information about relax you can subscribe to the list by visting the information page at <https://mail.gna.org/listinfo/relax-announce/>. Previous announcements can be viewed at <https://mail.gna.org/public/relax-announce/>.

### 3.2.2 relax-users

If you would like to ask questions about relax, discuss certain features, receive help, or to communicate on any other subject related to relax the mailing list “relax-users at gna.org” is the place to post your message. To subscribe to the list go to the relax-users information page at <https://mail.gna.org/listinfo/relax-users/>. You can also browse the mailing list archives at <https://mail.gna.org/public/relax-users/>.

### 3.2.3 relax-devel

A second mailing list exists for posts relating to the development of relax. The list is “relax-devel at gna.org” and to subscribe go to the relax-devel information page at <https://mail.gna.org/listinfo/relax-devel/>. Feature requests, program design, or any other posts relating to relax’s structure or code should be sent to this list instead. The mailing list archives can be browsed at <https://mail.gna.org/public/relax-devel/>.

### 3.2.4 relax-commits

One last mailing list is the relax commits list. This list is reserved for automatically generated posts created by the version control software which looks after the relax source code and these web pages. If you would like to become a developer you can subscribe to the list at relax-commits information page <https://mail.gna.org/listinfo/relax-commits/>. The list can also be browsed at <https://mail.gna.org/public/relax-commits/>.

### 3.2.5 Replying to a message

When replying to a message on these lists remember to hit ‘respond to all’ so that the mailing list is included in the CC field. Otherwise your message will only be sent to the original poster and not return back to the list. Only messages to relax-users and relax-devel will be accepted. If you are using Gmail’s web based interface, please do not click on ‘Edit Subject’ as this currently mangles the email headers, creates a new thread on the mailing list, and makes it difficult to follow the thread.

## 3.3 Reporting bugs

One of the philosophies in the construction of relax is that if there is something which is not immediately obvious then that is considered a design bug. If any flaws in relax are uncovered including general design flaws, bugs in the code, or documentation issues these can be reported within relax’s bug tracker system. The link to submit a bug is <https://gna.org/bugs/?group=relax&func=additem> while the main page for browsing, submitting, viewing the statistics, or searching through the database is at <https://gna.org/bugs/?group=relax>. Please do not report bugs to personal email addresses or to the mailing lists.

When reporting a bug please include as much information as possible so that the problem can be reproduced. Include information such as the release version or the revision number if the repository sources are being used. Also include all the steps performed in order to trigger the bug. Attachment of files is allowed so scripts and subsets of the input data can be included. However please do not attach large files to the report. Prior to reporting the bug try to make sure that the problem is indeed a bug and if you have any doubts please feel free to ask on the relax-users mailing list. To avoid duplicates be sure that the bug has not already been submitted to the bug tracker. You can search the bugs from the page <https://gna.org/project/search.php?group=relax>.

Once the bug has been confirmed by one of the relax developers you may speed up the resolution of the problem by trying to fixing the bug yourself. If you do wish to play with the source code and try to fix the issue see the relax development chapter of this manual on how to check out the latest sources, how to generate a patch (which is just the output of diff in the ‘unified’ format), and the guidelines for the format of the code.

### 3.4 Latest sources – the relax repositories

relax’s source code is kept within a version control system called Subversion (<http://subversion.tigris.org/>). Subversion or SVN allows fine control over the development of the program. The repository contains all information about every change ever made to the program. To learn more about the system the Subversion book located at <http://svnbook.red-bean.com/> is a good place to start. The contents of the relax repository can be viewed on-line at <http://svn.gna.org/viewcvs/relax/>. The current sources, assuming that the most recent minor version number is 1.2, can be downloaded using the SVN protocol by typing

```
$ svn co svn://svn.gna.org/svn/relax/1.2 relax
```

however if this does not work, try the command

```
$ svn co http://svn.gna.org/svn/relax/1.2 relax
```

to download using the HTTP protocol. The entire relax repository is backed up daily to <http://svn.gna.org/daily/relax.dump.gz>.

### 3.5 News

Summaries of the latest news on relax can be found on the relax web site <https://gna.org/projects/relax>. However more information can be found at the dedicated news page <https://gna.org/news/?group=relax>.

### 3.6 The relax distribution archives

The relax distribution archives, the files to download to install relax, can be found at <http://download.gna.org/relax/>. If a compiled binary distribution for your architecture

does not exist you are welcome to create this distribution yourself and submit it for inclusion in the relax project. To do this a number of steps are required. Firstly, the code to each relax release or version resides in the ‘tags’ directory of the relax repository. To check out version 1.2.0 for example type

```
$ svn co svn://svn.gna.org/svn/relax/tags/1.2.0 relax
```

Again the sources are available through HTTP by typing

```
$ svn co http://svn.gna.org/svn/relax/tags/1.2.0 relax
```

The binary distribution can then be created for your architecture by shifting to the main directory of the checked out sources and typing

```
$ cd relax
$ scons binary_dist
```

At the end SCons will attempt to make a GPG signature for the newly created archive. However this will fail as the current relax private GPG key is not available for security reasons. If the SCons command fails, excluding the GPG signing, please submit a bug report with as much information possible including the details described next to <https://gna.org/bugs/?group=relax&func=additem> (the python and SCons version numbers may also be useful). Once the file has been created post a message to the relax development mailing list describing the compilation and the creation of the archive, the relax version number, the machine architecture, operating system, and the name of the new file. Do not attach the file though. You will then receive a response explaining where to send the file to. For security the archive will be thoroughly checked and if the source code is identical to that in the repository and the C modules are okay, the file will be GPG signed and uploaded to <http://download.gna.org/relax/>.



## Chapter 4

# Calculating the NOE

### 4.1 Introduction

The calculation of NOE values is a straight forward and quick procedure which involves two components – the calculation of the value itself and the calculation of the errors. To understand the steps involved the execution of a sample NOE calculation script will be followed in detail.

### 4.2 The sample script

```
# Script for calculating NOEs.

# Create the data pipe.
pipe.create('NOE', 'noe')

# Load the sequence from a PDB file.
structure.read_pdb(name, 'Ap4Aase_new_3.pdb')
structure.load_spins(spin_id='@N')
# Load the reference spectrum and saturated spectrum peak intensities.
noe.read(file='ref.list', spectrum_type='ref')
noe.read(file='sat.list', spectrum_type='sat')

# Set the errors.
noe.error(error=3600, spectrum_type='ref')
noe.error(error=3000, spectrum_type='sat')

# Individual residue errors.
noe.error(error=122000, spectrum_type='ref', res_num=114)
noe.error(error=8500, spectrum_type='sat', res_num=114)

# Deselect unresolved residues.
deselect.read(file='unresolved')
```

```

# Calculate the NOEs.
calc()

# Save the NOEs.
value.write(param='noe', file='noe.out', force=True)

# Create grace files.
grace.write(y_data_type='ref', file='ref.agr', force=True)
grace.write(y_data_type='sat', file='sat.agr', force=True)
grace.write(y_data_type='noe', file='noe.agr', force=True)

# View the grace files.
grace.view(file='ref.agr')
grace.view(file='sat.agr')
grace.view(file='noe.agr')

# Write the results.
results.write(file='results', dir=None, force=True)

# Save the program state.
state.save('save', force=True)

```

### 4.3 Initialisation of the data pipe

The data pipe is simply created by the command

```
pipe.create('NOE', 'noe')
```

This user function will then create a NOE calculation specific data pipe labelled 'NOE'. The second argument sets the pipe type to that of the NOE calculation. Setting the pipe type is important so that the program knows which user functions are compatible with the data pipe, for example the function `minimise()` is meaningless in this sample script as the NOE values are directly calculated rather than optimised.

### 4.4 Loading the data

The first thing which need to be completed prior to any residue specific command is to generate the sequence from a PDB file. In this case the command

```
structure.read_pdb(name, 'Ap4Aase_new_3.pdb')
```

will load the PDB file 'Ap4Aase\_new\_3.pdb' into relax. Then

```
structure.load_spins(spin_id='@N')
```

will generate the molecule, residue, and spin sequence for the current data pipe. In this situation there will be a single spin system per residue generated corresponding to the backbone amide nitrogens. Although the PDB coordinates have been loaded into the program, the structural information serves no purpose when calculating NOE values.

The next two commands

```
noe.read(file='ref.list', spectrum_type='ref')
noe.read(file='sat.list', spectrum_type='sat')
```

load the peak heights of the reference and saturated NOE experiments (although the volume could be used instead). The keyword argument `format` has not been specified hence the default format of a Sparky peak list (saved after typing `'lt'`) is assumed. If the program XEasy was used to analyse the spectra the argument `format='xeasy'` is necessary. The first column of the file should be the Sparky assignment string and it is assumed that the 4<sup>th</sup> column contains either the peak height or peak volume. For example:

| Assignment | w1      | w2    | Data Height |
|------------|---------|-------|-------------|
| LEU3N-HN   | 122.454 | 8.397 | 129722      |
| GLY4N-HN   | 111.999 | 8.719 | 422375      |
| SER5N-HN   | 115.085 | 8.176 | 384180      |
| MET6N-HN   | 120.934 | 8.812 | 272100      |
| ASP7N-HN   | 122.394 | 8.750 | 174970      |
| SER8N-HN   | 113.916 | 7.836 | 218762      |
| GLU11N-HN  | 122.194 | 8.604 | 30412       |
| GLY12N-HN  | 110.525 | 9.028 | 90144       |

If you have any other format you would like read by relax please send an email to the relax development mailing list detailing the software used, the format of the file (specifically where the residue number and peak intensity are located), and possibly attaching an example of the file itself.

## 4.5 Setting the errors

In this example the errors were measured from the base plain noise. The Sparky RMSD function was used to estimate the maximal noise levels across the spectrum in regions containing no peaks. For the reference spectrum the RMSD was approximately 3600 whereas in the saturated spectrum the RMSD was 3000. These errors are set by the commands

```
noe.error(error=3600, spectrum_type='ref')
noe.error(error=3000, spectrum_type='sat')
```

For the residue G114, the noise levels are significantly increased compared to the rest of the protein as the peak is located close to the water signal. The higher errors for this residue are specified by the commands

```
noe.error(error=122000, spectrum_type='ref', res_num=114)
noe.error(error=8500, spectrum_type='sat', res_num=114)
```

## 4.6 Unresolved residues

As the peaks of certain residues overlap to such an extent that the heights cannot be resolved, a simple text file was created called `unresolved` in which each line consists of a

single residue number. By using the command

```
deselect.read(name, file='unresolved')
```

all residues in the file `unresolved` are excluded from the analysis.

## 4.7 The NOE

At this point the NOE can be calculated. The user function

```
calc()
```

will calculate both the NOE and the errors. The NOE value will be calculated using the formula

$$NOE = \frac{I_{sat}}{I_{ref}}, \quad (4.1)$$

where  $I_{sat}$  is the intensity of the peak in the saturated spectrum and  $I_{ref}$  is that of the reference spectrum. The error is calculated by

$$\sigma_{NOE} = \sqrt{\frac{(\sigma_{sat} \cdot I_{ref})^2 + (\sigma_{ref} \cdot I_{sat})^2}{I_{ref}^2}}, \quad (4.2)$$

where  $\sigma_{sat}$  and  $\sigma_{ref}$  are the peak intensity errors in the saturated and reference spectra respectively. To create a file of the NOEs the command

```
value.write(param='noe', file='noe.out', force=True)
```

will create a file called `noe.out` with the NOE values and errors. The force flag will cause any file with the same name to be overwritten. An example of the format of `noe.out` is

| Num | Name | Value               | Error                |
|-----|------|---------------------|----------------------|
| 1   | GLY  | None                | None                 |
| 2   | PRO  | None                | None                 |
| 3   | LEU  | None                | None                 |
| 4   | GLY  | 0.12479588727508535 | 0.020551827436105764 |
| 5   | SER  | 0.42240815792914105 | 0.02016346825976852  |
| 6   | MET  | 0.45281703194372114 | 0.026272719841642134 |
| 7   | ASP  | 0.60727570079478255 | 0.032369427242382849 |
| 8   | SER  | 0.63871921623680161 | 0.024695665815261791 |
| 9   | PRO  | None                | None                 |
| 10  | PRO  | None                | None                 |
| 11  | GLU  | None                | None                 |
| 12  | GLY  | 0.92927160307645906 | 0.059569089743604184 |
| 13  | TYR  | 0.88832516377296256 | 0.044119641308479306 |
| 14  | ARG  | 0.84945042565860407 | 0.060533543601110441 |

## 4.8 Viewing the results

Any two dimensional data set can be plotted in relax in conjunction with the program [Grace](#). The program is also known as Xmgrace and was previously known as ACE/gr or

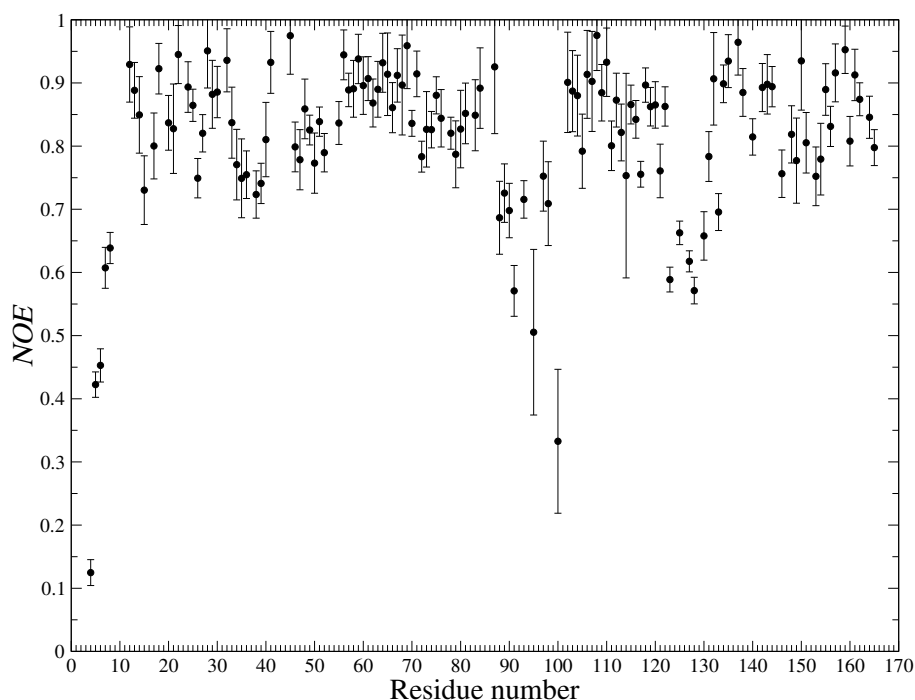


Figure 4.1: A Grace plot of the NOE value and error against the residue number. This is an example of the output of the user function `grace.write()`.

Xmgr. The highly flexible relax user function `grace.write` is capable of producing 2D plots of any x-y data sets. The three commands

```
grace.write(y_data_type='ref', file='ref.agr', force=True)
grace.write(y_data_type='sat', file='sat.agr', force=True)
grace.write(y_data_type='noe', file='noe.agr', force=True)
```

create three separate plots of the peak intensity of the reference and saturated spectra as well as the NOE. The x-axis in all three defaults to the residue number. As the x and y-axes can be any parameter the command

```
grace.write(x_data_type='ref', y_data_type='sat', file='ref_vs_sat.agr', force=True)
```

would create a plot of the reference versus the saturated intensity with one point per residue. Returning to the sample script three Grace data files are created `ref.agr`, `sat.agr`, and `noe.agr` and placed in the default directory `./grace`. These can be visualised by opening the file within Grace. However relax will do that for you with the commands

```
grace.view(file='ref.agr')
grace.view(file='sat.agr')
grace.view(file='noe.agr')
```

An example of the output after modifying the axes is shown in figure 4.1.



## Chapter 5

# The $R_1$ and $R_2$ relaxation rates – relaxation curve-fitting

### 5.1 Introduction

Relaxation curve-fitting involves a number of steps including the loading of data, the calculation of both the average peak intensity across replicated spectra and the standard deviations of those peak intensities, selection of the experiment type, optimisation of the parameters of the fit, Monte Carlo simulations to find the parameter errors, and saving and viewing the results. To simplify the process a sample script will be followed step by step as was done with the NOE calculation.

### 5.2 The sample script

```
# Script for relaxation curve-fitting.

# Create the 'rx' data pipe.
pipe.create('rx', 'relax_fit')

# Load the backbone amide 15N spins from a PDB file.
structure.read_pdb('Ap4Aase_new_3.pdb')
structure.load_spins(spin_id='@N')

# Load the peak intensities.
relax_fit.read(file='T2_ncyc1.list', relax_time=0.0176)
relax_fit.read(file='T2_ncyc1b.list', relax_time=0.0176)
relax_fit.read(file='T2_ncyc2.list', relax_time=0.0352)
relax_fit.read(file='T2_ncyc4.list', relax_time=0.0704)
relax_fit.read(file='T2_ncyc4b.list', relax_time=0.0704)
relax_fit.read(file='T2_ncyc6.list', relax_time=0.1056)
relax_fit.read(file='T2_ncyc9.list', relax_time=0.1584)
relax_fit.read(file='T2_ncyc9b.list', relax_time=0.1584)
```

```

relax_fit.read(file='T2_ncyc11.list', relax_time=0.1936)
relax_fit.read(file='T2_ncyc11b.list', relax_time=0.1936)

# Calculate the peak intensity averages and the standard deviation of all spectra.
relax_fit.mean_and_error()

# Deselect unresolved residues.
deselect.read(file='unresolved')

# Set the relaxation curve type.
relax_fit.select_model('exp')

# Grid search.
grid_search(inc=11)

# Minimise.
minimise('simplex', scaling=False, constraints=False)

# Monte Carlo simulations.
monte_carlo.setup(number=500)
monte_carlo.create_data()
monte_carlo.initial_values()
minimise('simplex', scaling=False, constraints=False)
monte_carlo.error_analysis()

# Save the relaxation rates.
value.write(param='rx', file='rx.out', force=True)

# Grace plots of the relaxation rate.
grace.write(y_data_type='rx', file='rx.agr', force=True)
grace.view(file='rx.agr')

# Save the program state.
state.save(file='rx.save', force=True)

```

### 5.3 Initialisation of the data pipe and loading of the data

The start of this sample script is very similar to that of the NOE calculation on page [22](#). The command

```
pipe.create('rx', 'relax_fit')
```

initialises the data pipe labelled 'rx'. The data pipe type is set to relaxation curve-fitting by the argument 'relax\_fit'. The backbone amide nitrogen sequence is extracted from a PDB file using the same commands as the NOE calculation script

```

structure.read_pdb(name, 'Ap4Aase_new_3.pdb')
structure.load_spins(spin_id='@N')

```



To load the peak intensities into relax the user function `relax_fit.read` is executed. Two important keyword arguments to this command are the file name and the relaxation time period of the experiment in seconds. It is assumed that the file format is that of a Sparky peak list. Using the format argument, this can be changed to XEasy text window output format. To be able to import any other type of format please send an email to the relax development mailing list with the details of the format. Adding support for new formats is trivial. The following series of commands will load peak intensities from six different relaxation periods, four of which have been duplicated

```
relax_fit.read(file='T2_ncyc1.list', relax_time=0.0176)
relax_fit.read(file='T2_ncyc1b.list', relax_time=0.0176)
relax_fit.read(file='T2_ncyc2.list', relax_time=0.0352)
relax_fit.read(file='T2_ncyc4.list', relax_time=0.0704)
relax_fit.read(file='T2_ncyc4b.list', relax_time=0.0704)
relax_fit.read(file='T2_ncyc6.list', relax_time=0.1056)
relax_fit.read(file='T2_ncyc9.list', relax_time=0.1584)
relax_fit.read(file='T2_ncyc9b.list', relax_time=0.1584)
relax_fit.read(file='T2_ncyc11.list', relax_time=0.1936)
relax_fit.read(file='T2_ncyc11b.list', relax_time=0.1936)
```

The format for the Sparky peak list is assumed to have the intensity value in the 4<sup>th</sup> column, e.g.:

| Assignment | w1      | w2    | Data | Height |
|------------|---------|-------|------|--------|
| LEU3N-HN   | 122.454 | 8.397 |      | 129722 |
| GLY4N-HN   | 111.999 | 8.719 |      | 422375 |
| SER5N-HN   | 115.085 | 8.176 |      | 384180 |
| MET6N-HN   | 120.934 | 8.812 |      | 272100 |
| ASP7N-HN   | 122.394 | 8.750 |      | 174970 |
| SER8N-HN   | 113.916 | 7.836 |      | 218762 |
| GLU11N-HN  | 122.194 | 8.604 |      | 30412  |
| GLY12N-HN  | 110.525 | 9.028 |      | 90144  |

## 5.4 The rest of the setup

Once all the peak intensity data has been loaded a few calculations are required prior to optimisation. Firstly the peak intensities for individual residues needs to be averaged across replicated spectra. The peak intensity errors also have to be calculated using the standard deviation formula. These two operations are executed by the user function

```
relax_fit.mean_and_error()
```

Any residues which cannot be resolved due to peak overlap were included in a file called 'unresolved'. This file consists solely of one residue number per line. These residues are excluded from the analysis by the user function

```
deselect.read(file='unresolved')
```

Finally the experiment type is specified by the command

```
relax_fit.select_model('exp')
```

The argument ‘**exp**’ sets the relaxation curve to a two parameter  $\{R_x, I_0\}$  exponential which decays to zero. The formula of this function is

$$I(t) = I_0 e^{-R_x \cdot t}, \quad (5.1)$$

where  $I(t)$  is the peak intensity at any time point  $t$ ,  $I_0$  is the initial intensity, and  $R_x$  is the relaxation rate (either the  $R_1$  or  $R_2$ ). Changing the user function argument to ‘**inv**’ will select the inversion recovery experiment. This curve consists of three parameters  $\{R_1, I_0, I_\infty\}$  and does not decay to zero. The formula is

$$I(t) = I_\infty - I_0 e^{-R_1 \cdot t}. \quad (5.2)$$

## 5.5 Optimisation

Now that everything has been setup minimisation can be used to optimise the parameter values. Firstly a grid search is applied to find a rough starting position for the subsequent optimisation algorithm. Eleven increments per dimension of the model (in this case the two dimensions  $\{R_x, I_0\}$ ) is sufficient. The user function for executing the grid search is

```
grid_search(inc=11)
```

The next step is to select one of the minimisation algorithms to optimise the model parameters. Currently for relaxation curve-fitting only simplex minimisation is supported. This is because the relaxation curve-fitting C module is incomplete only implementing the chi-squared function. The chi-squared gradient (the vector of first partial derivatives) and chi-squared Hessian (the matrix of second partial derivatives) are not yet implemented in the C modules and hence optimisation algorithms which only employ function calls are supported. Simplex minimisation is the only technique in relax which fits this criterion. In addition constraints cannot be used as the constraint algorithm is dependent on gradient calls. Therefore the minimisation command for relaxation curve-fitting is forced to be

```
minimise('simplex', constraints=False)
```

## 5.6 Error analysis

Only one technique adequately estimates parameter errors when the parameter values were found by optimisation – Monte Carlo simulations. In relax this can be implemented by using a series of functions from the `monte_carlo` user function class. Firstly the number of simulations needs to be set

```
monte_carlo.setup(number=500)
```

For each simulation, randomised relaxation curves will be fit using exactly the same methodology as the original exponential curves. These randomised curves are created by back calculation from the fitted model parameter values and then each point on the curve randomised using the error values set earlier in the script

```
monte_carlo.create_data()
```

As a grid search for each simulation would be too computationally expensive, the starting point for optimisation for each simulation can be set to the position of the optimised parameter values of the model

```
monte_carlo.initial_values()
```

Then exactly the same optimisation as was used for the model can be performed

```
minimise('simplex', constraints=False)
```

The parameter errors are then determined as the standard deviation of the optimised parameter values of the simulations

```
monte_carlo.error_analysis()
```

## 5.7 Finishing off

To finish off, the script first saves the relaxation rates together with their errors in a simple text file

```
value.write(param='rx', file='rx.out', force=True)
```

Grace plots are created and viewed

```
grace.write(y_data_type='rx', file='rx.agr', force=True)
```

```
grace.view(file='rx.agr')
```

and finally the program state is saved for future reference

```
state.save(file='rx.save', force=True)
```



## Chapter 6

# Model-free analysis

### 6.1 Theory

#### 6.1.1 The chi-squared function – $\chi^2(\theta)$

For the minimisation of the model-free models a chain of calculations, each based on a different theory, is required. At the highest level the equation which is actually minimised is the chi-squared function

$$\chi^2(\theta) = \sum_{i=1}^n \frac{(R_i - R_i(\theta))^2}{\sigma_i^2}, \quad (6.1)$$

where the index  $i$  is the summation index ranging over all the experimentally collected relaxation data of all residues used in the analysis;  $R_i$  belongs to the relaxation data set  $R$  for an individual residue, a collection of residues, or the entire macromolecule and includes the  $R_1$ ,  $R_2$ , and NOE data at all field strengths;  $R_i(\theta)$  is the back-calculated relaxation value belonging to the set  $R(\theta)$ ;  $\theta$  is the model parameter vector which when minimised is denoted by  $\hat{\theta}$ ; and  $\sigma_i$  is the experimental error.

The significance of the chi-squared equation (6.1) is that the function returns a single value which is then minimised by the optimisation algorithm to find the model-free parameter values of the given model.

#### 6.1.2 The transformed relaxation equations – $R_i(\theta)$

The chi-squared equation is itself dependent on the relaxation equations through the back-calculated relaxation data  $R(\theta)$ . Letting the relaxation values of the set  $R(\theta)$  be the  $R_1(\theta)$ ,  $R_2(\theta)$ , and  $\text{NOE}(\theta)$  an additional layer of abstraction can be used to simplify the calculation of the gradients and Hessians. This involves decomposing the NOE equation into the cross relaxation rate constant  $\sigma_{\text{NOE}}(\theta)$  and the auto relaxation rate  $R_1(\theta)$ . Taking

equation (6.6) below the transformed relaxation equations are

$$R_1(\theta) = R'_1(\theta), \quad (6.2a)$$

$$R_2(\theta) = R'_2(\theta), \quad (6.2b)$$

$$\text{NOE}(\theta) = 1 + \frac{\gamma_H}{\gamma_X} \frac{\sigma_{\text{NOE}}(\theta)}{R_1(\theta)}. \quad (6.2c)$$

whereas the relaxation equations are the  $R_1(\theta)$ ,  $R_2(\theta)$ ,  $\sigma_{\text{NOE}}(\theta)$ .

### 6.1.3 The relaxation equations – $R'_i(\theta)$

The relaxation values of the set  $R'(\theta)$  include the spin-lattice, spin-spin, and cross-relaxation rates at all field strengths. These rates are respectively (Abragam, 1961)

$$R_1(\theta) = d \left( J(\omega_H - \omega_X) + 3J(\omega_X) + 6J(\omega_H + \omega_X) \right) + cJ(\omega_X), \quad (6.3a)$$

$$R_2(\theta) = \frac{d}{2} \left( 4J(0) + J(\omega_H - \omega_X) + 3J(\omega_X) + 6J(\omega_H) \right. \\ \left. + 6J(\omega_H + \omega_X) \right) + \frac{c}{6} \left( 4J(0) + 3J(\omega_X) \right) + R_{ex}, \quad (6.3b)$$

$$\sigma_{\text{NOE}}(\theta) = d \left( 6J(\omega_H + \omega_X) - J(\omega_H - \omega_X) \right), \quad (6.3c)$$

where  $J(\omega)$  is the power spectral density function and  $R_{ex}$  is the relaxation due to chemical exchange. The dipolar and CSA constants are defined in SI units as

$$d = \frac{1}{4} \left( \frac{\mu_0}{4\pi} \right)^2 \frac{(\gamma_H \gamma_X \hbar)^2}{\langle r^6 \rangle}, \quad (6.4)$$

$$c = \frac{(\omega_H \Delta\sigma)^2}{3}, \quad (6.5)$$

where  $\mu_0$  is the permeability of free space,  $\gamma_H$  and  $\gamma_X$  are the gyromagnetic ratios of the  $H$  and  $X$  spins respectively,  $\hbar$  is Planck's constant divided by  $2\pi$ ,  $r$  is the bond length, and  $\Delta\sigma$  is the chemical shift anisotropy measured in ppm. The cross-relaxation rate  $\sigma_{\text{NOE}}$  is related to the steady state NOE by the equation

$$\text{NOE}(\theta) = 1 + \frac{\gamma_H}{\gamma_X} \frac{\sigma_{\text{NOE}}(\theta)}{R_1(\theta)}. \quad (6.6)$$

### 6.1.4 The spectral density functions – $J(\omega)$

The relaxation equations are themselves dependent on the calculation of the spectral density values  $J(\omega)$ . Within model-free analysis these are modelled by the original model-free formula (Lipari and Szabo, 1982a,b)

$$J(\omega) = \frac{2}{5} \sum_{i=-k}^k c_i \cdot \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2} \right), \quad (6.7)$$

where  $S^2$  is the square of the Lipari and Szabo generalised order parameter and  $\tau_e$  is the effective correlation time. The order parameter reflects the amplitude of the motion and the correlation time in an indication of the time scale of that motion. The theory was extended by [Clore et al. \(1990\)](#) by the modelling of two independent internal motions using the equation

$$J(\omega) = \frac{2}{5} \sum_{i=-k}^k c_i \cdot \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega\tau_f\tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega\tau_s\tau_i)^2} \right). \quad (6.8)$$

where  $S_f^2$  and  $\tau_f$  are the amplitude and timescale of the faster of the two motions whereas  $S_s^2$  and  $\tau_s$  are those of the slower motion.  $S_f^2$  and  $S_s^2$  are related by the formula  $S^2 = S_f^2 \cdot S_s^2$ .

### 6.1.5 Brownian rotational diffusion

In equations (6.7) and (6.8) the generic Brownian diffusion NMR correlation function presented in [d'Auvergne \(2006\)](#) has been used. This function is

$$C(\tau) = \frac{1}{5} \sum_{i=-k}^k c_i \cdot e^{-\tau/\tau_i}, \quad (6.9)$$

where the summation index  $i$  ranges over the number of exponential terms within the correlation function. This equation is generic in that it can describe the diffusion of an ellipsoid, a spheroid, or a sphere.

### Diffusion as an ellipsoid

For the ellipsoid defined by the parameter set  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r, \alpha, \beta, \gamma\}$  the variable  $k$  is equal to two and therefore the index  $i \in \{-2, -1, 0, 1, 2\}$ . The geometric parameters  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r\}$  are defined as

$$\mathfrak{D}_{iso} = \frac{1}{3}(\mathfrak{D}_x + \mathfrak{D}_y + \mathfrak{D}_z), \quad (6.10a)$$

$$\mathfrak{D}_a = \mathfrak{D}_z - \frac{1}{2}(\mathfrak{D}_x + \mathfrak{D}_y), \quad (6.10b)$$

$$\mathfrak{D}_r = \frac{\mathfrak{D}_y - \mathfrak{D}_x}{2\mathfrak{D}_a}, \quad (6.10c)$$

and are constrained by

$$0 < \mathfrak{D}_{iso} < \infty, \quad (6.11a)$$

$$0 \leq \mathfrak{D}_a < \frac{\mathfrak{D}_{iso}}{\frac{1}{3} + \mathfrak{D}_r} \leq 3\mathfrak{D}_{iso}, \quad (6.11b)$$

$$0 \leq \mathfrak{D}_r \leq 1. \quad (6.11c)$$

The orientational parameters  $\{\alpha, \beta, \gamma\}$  are the Euler angles using the z-y-z rotation notation.

The five weights  $c_i$  are defined as

$$c_{-2} = \frac{1}{4}(d - e), \quad (6.12a)$$

$$c_{-1} = 3\delta_y^2\delta_z^2, \quad (6.12b)$$

$$c_0 = 3\delta_x^2\delta_z^2, \quad (6.12c)$$

$$c_1 = 3\delta_x^2\delta_y^2, \quad (6.12d)$$

$$c_2 = \frac{1}{4}(d + e), \quad (6.12e)$$

where

$$d = 3(\delta_x^4 + \delta_y^4 + \delta_z^4) - 1, \quad (6.13)$$

$$e = \frac{1}{\Re} \left[ (1 + 3\mathfrak{D}_r) (\delta_x^4 + 2\delta_y^2\delta_z^2) + (1 - 3\mathfrak{D}_r) (\delta_y^4 + 2\delta_x^2\delta_z^2) - 2(\delta_z^4 + 2\delta_x^2\delta_y^2) \right], \quad (6.14)$$

and where

$$\Re = \sqrt{1 + 3\mathfrak{D}_r^2}. \quad (6.15)$$

The five correlation times  $\tau_i$  are

$$1/\tau_{-2} = 6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\Re, \quad (6.16a)$$

$$1/\tau_{-1} = 6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r), \quad (6.16b)$$

$$1/\tau_0 = 6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r), \quad (6.16c)$$

$$1/\tau_1 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a, \quad (6.16d)$$

$$1/\tau_2 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\Re. \quad (6.16e)$$

### Diffusion as a spheroid

The variable  $k$  is equal to one in the case of the spheroid defined by the parameter set  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \theta, \phi\}$ , hence  $i \in \{-1, 0, 1\}$ . The geometric parameters  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a\}$  are defined as

$$\mathfrak{D}_{iso} = \frac{1}{3}(\mathfrak{D}_{\parallel} + 2\mathfrak{D}_{\perp}), \quad (6.17a)$$

$$\mathfrak{D}_a = \mathfrak{D}_{\parallel} - \mathfrak{D}_{\perp}. \quad (6.17b)$$

and are constrained by

$$0 < \mathfrak{D}_{iso} < \infty, \quad (6.18a)$$

$$-\frac{3}{2}\mathfrak{D}_{iso} < \mathfrak{D}_a < 3\mathfrak{D}_{iso}. \quad (6.18b)$$

The orientational parameters  $\{\theta, \phi\}$  are the spherical angles defining the orientation of the major axis of the diffusion frame within the lab frame.



The three weights  $c_i$  are

$$c_{-1} = \frac{1}{4}(3\delta_z^2 - 1)^2, \quad (6.19a)$$

$$c_0 = 3\delta_z^2(1 - \delta_z^2), \quad (6.19b)$$

$$c_1 = \frac{3}{4}(\delta_z^2 - 1)^2. \quad (6.19c)$$

The five correlation times  $\tau_i$  are

$$1/\tau_{-1} = 6\mathfrak{D}_{iso} - 2\mathfrak{D}_a, \quad (6.20a)$$

$$1/\tau_0 = 6\mathfrak{D}_{iso} - \mathfrak{D}_a, \quad (6.20b)$$

$$1/\tau_1 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a. \quad (6.20c)$$

### Diffusion as a sphere

In the situation of a molecule diffusing as a sphere either described by the single parameter  $\tau_m$  or  $\mathfrak{D}_{iso}$ , the variable  $k$  is equal to zero. Therefore  $i \in \{0\}$ . The single weight  $c_0$  is equal to one and the single correlation time  $\tau_0$  is equivalent to the global tumbling time  $\tau_m$  given by

$$1/\tau_m = 6\mathfrak{D}_{iso}. \quad (6.21)$$

This is diffusion equation presented in [Bloembergen et al. \(1948\)](#).

#### 6.1.6 The model-free models

Extending the list of models given in [Mandel et al. \(1995\)](#); [Fushman et al. \(1997\)](#); [Orekhov et al. \(1999\)](#); [Korzhnev et al. \(2001\)](#); [Zhuravleva et al. \(2004\)](#), the models built into relax include

$$m0 = \{\}, \quad (6.22.0)$$

$$m1 = \{S^2\}, \quad (6.22.1)$$

$$m2 = \{S^2, \tau_e\}, \quad (6.22.2)$$

$$m3 = \{S^2, R_{ex}\}, \quad (6.22.3)$$

$$m4 = \{S^2, \tau_e, R_{ex}\}, \quad (6.22.4)$$

$$m5 = \{S^2, S_f^2, \tau_s\}, \quad (6.22.5)$$

$$m6 = \{S^2, \tau_f, S_f^2, \tau_s\}, \quad (6.22.6)$$

$$m7 = \{S^2, S_f^2, \tau_s, R_{ex}\}, \quad (6.22.7)$$

$$m8 = \{S^2, \tau_f, S_f^2, \tau_s, R_{ex}\}, \quad (6.22.8)$$

$$m9 = \{R_{ex}\}. \quad (6.22.9)$$

The parameter  $R_{ex}$  is scaled quadratically with field strength in these models as it is assumed to be fast. In the set theory notation, the model-free model for the spin system  $i$  is represented by the symbol  $\mathfrak{F}_i$ . Through the addition of the local  $\tau_m$  to each of these

models, only the component of Brownian rotational diffusion experienced by the spin system is probed. These models, represented in set notation by the symbol  $\mathfrak{T}_i$ , are

$$tm0 = \{\tau_m\}, \quad (6.23.0)$$

$$tm1 = \{\tau_m, S^2\}, \quad (6.23.1)$$

$$tm2 = \{\tau_m, S^2, \tau_e\}, \quad (6.23.2)$$

$$tm3 = \{\tau_m, S^2, R_{ex}\}, \quad (6.23.3)$$

$$tm4 = \{\tau_m, S^2, \tau_e, R_{ex}\}, \quad (6.23.4)$$

$$tm5 = \{\tau_m, S^2, S_f^2, \tau_s\}, \quad (6.23.5)$$

$$tm6 = \{\tau_m, S^2, \tau_f, S_f^2, \tau_s\}, \quad (6.23.6)$$

$$tm7 = \{\tau_m, S^2, S_f^2, \tau_s, R_{ex}\}, \quad (6.23.7)$$

$$tm8 = \{\tau_m, S^2, \tau_f, S_f^2, \tau_s, R_{ex}\}, \quad (6.23.8)$$

$$tm9 = \{\tau_m, R_{ex}\}. \quad (6.23.9)$$

### 6.1.7 Model-free optimisation theory

#### The model-free space

The optimisation of the parameters of an arbitrary model is dependent on a function  $f$  which takes the current parameter values  $\theta \in \mathbb{R}^n$  and returns a single real value  $f(\theta) \in \mathbb{R}$  corresponding to position  $\theta$  in the  $n$ -dimensional space. For it is that single value which is minimised as

$$\hat{\theta} = \arg \min_{\theta} f(\theta), \quad (6.24)$$

where  $\hat{\theta}$  is the parameter vector which is equal to the argument which minimises the function  $f(\theta)$ . In model-free analysis  $f(\theta)$  is the chi-squared equation

$$\chi^2(\theta) = \sum_{i=1}^n \frac{(R_i - R_i(\theta))^2}{\sigma_i^2}, \quad (6.25)$$

where  $i$  is the summation index,  $R_i$  is the experimental relaxation data which belongs to the data set  $R$  and includes the  $R_1$ ,  $R_2$ , and NOE values at all field strengths,  $R_i(\theta)$  is the back calculated relaxation data belonging to the set  $R(\theta)$ , and  $\sigma_i$  is the experimental error. For the optimisation of the model-free parameters while the diffusion tensor is held fixed, the summation index ranges over the relaxation data of an individual residue. If the diffusion parameters are optimised simultaneously with the model-free parameters the summation index ranges over all relaxation data of all selected residues of the macromolecule.

Given the current parameter values the model-free function provided to the algorithm will calculate the value of the model-free spectral density function  $J(\omega)$  at the five frequencies which induce NMR relaxation by using Equations (6.7) and (6.8). The theoretical  $R_1$ ,  $R_2$ , and NOE values are then back-calculated using Equations (6.3a), (6.3b), (6.3c), and (6.6). Finally, the chi-squared value is calculated using Equation (6.25).

### Topology of the space

The problem of finding the minimum is complicated by the fact that optimisation algorithms are blind to the curvature of the complete space. Instead they rely on topological information about the current and, sometimes, the previous parameter positions in the space. The techniques use this information to walk iteratively downhill to the minimum. Very few optimisation algorithms rely solely on the function value, conceptually the height of the space, at the current position. Most techniques also utilise the gradient at the current position. Although symbolically complex in the case of model-free analysis, the gradient can simply be calculated as the vector of first partial derivatives of the chi-squared equation with respect to each model-free parameter. The gradient is supplied as a second function to the algorithm which is then utilised in diverse ways by different optimisation techniques. The function value together with the gradient can be combined to construct a linear or planar description of the space at the current parameter position by first-order Taylor series approximation

$$f(\theta_k + x) \approx f_k + x^T \nabla f_k, \quad (6.26)$$

where  $f_k$  is the function value at the current parameter position  $\theta_k$ ,  $\nabla f_k$  is the gradient at the same position, and  $x$  is an arbitrary vector. By accumulating information from previous parameter positions a more comprehensive geometric description of the curvature of the space can be exploited by the algorithm for more efficient optimisation.

The best and most comprehensive description of the space is given by the quadratic approximation of the topology which is generated from the combination of the function value, the gradient, and the Hessian. From the second-order Taylor series expansion the quadratic model of the space is

$$f(\theta_k + x) \approx f_k + x^T \nabla f_k + \frac{1}{2} x^T \nabla^2 f_k x, \quad (6.27)$$

where  $\nabla^2 f_k$  is the Hessian, which is the symmetric matrix of second partial derivatives of the function, at the position  $\theta_k$ . As the Hessian is computationally expensive a number of optimisation algorithms try to approximate it.

To produce the gradient and Hessian required for model-free optimisation a large chain of first and second partial derivatives needs to be calculated. Firstly the partial derivatives of the spectral density functions (6.7) and (6.8) are necessary. Then the partial derivatives of the relaxation equations (6.3a) to (6.3c) followed by the NOE equation (6.6) are needed. Finally the partial derivative of the chi-squared formula (6.25) is required. These first and second partial derivatives, as well as those of the components of the Brownian diffusion correlation function for non-isotropic tumbling, are presented in Chapter 8.

### Optimisation algorithms

Prior to minimisation, all optimisation algorithms investigated require a starting position within the model-free space. This initial parameter vector is found by employing a coarse grid search – chi-squared values at regular positions spanning the space are calculated and the grid point with the lowest value becomes the starting position. The grid search

itself is an optimisation technique. As it is computationally expensive the number of grid points needs to be kept to a minimum. Hence the initial parameter values are a rough and imprecise approximation of the local minimum. Due to the complexity of the curvature of the model-free space, the grid point with the lowest chi-squared value may in fact be on the opposite side of the space to the local minimum.

Once the starting position has been determined by the grid search the optimisation algorithm can be executed. The number of algorithms developed within the mathematical field of optimisation is considerable. They can nevertheless be grouped into one of a small number of major categories based on the fundamental principles of the technique. These include the line search methods, the trust region methods, and the conjugate gradient methods. For more details on the algorithms described below see [Nocedal and Wright \(1999\)](#).

### Line search methods

The defining characteristic of a line search algorithm is to choose a search direction  $p_k$  and then to find the minimum along that vector starting from  $\theta_k$  ([Nocedal and Wright, 1999](#)). The distance travelled along  $p_k$  is the step length  $\alpha_k$  and the parameter values for the next iteration are

$$\theta_{k+1} = \theta_k + \alpha_k p_k. \quad (6.28)$$

The line search algorithm determines the search direction  $p_k$  whereas the value of  $\alpha_k$  is found using an auxiliary step-length selection algorithm.

One of the simplest line search methods is the steepest descent algorithm. The search direction is simply the negative gradient,  $p_k = -\nabla f_k$ , and hence the direction of maximal descent is always followed. This method is inefficient – the linear rate of convergence requires many iterations of the algorithm to reach the minimum and it is susceptible to being trapped on saddle points within the space.

The coordinate descent algorithms are a simplistic group of line search methods whereby the search directions alternate between vectors parallel to the parameter axes. For the back-and-forth coordinate descent the search directions cycle in one direction and then back again. For example for a three parameter model the search directions cycle  $\theta_1, \theta_2, \theta_3, \theta_2, \theta_1, \theta_2, \dots$ , which means that each parameter of the model is optimised one by one. The method becomes less efficient when approaching the minimum as the step length  $\alpha_k$  continually decreases (*ibid.*).

The quasi-Newton methods begin with an initial guess of the Hessian and update it at each iteration using the function value and gradient. Therefore the benefits of using the quadratic model of (6.27) are obtained without calculating the computationally expensive Hessian. The Hessian approximation  $B_k$  is updated using various formulae, the most common being the BFGS formula ([Broyden, 1970](#); [Fletcher, 1970](#); [Goldfarb, 1970](#); [Shanno, 1970](#)). The search direction is given by the equation  $p_k = -B_k^{-1} \nabla f_k$ . The quasi-Newton algorithms can attain a superlinear rate of convergence, being superior to the steepest descent or coordinate descent methods.

The most powerful line search method when close to the minimum is the Newton search direction

$$p_k = -\nabla^2 f_k^{-1} \nabla f_k. \quad (6.29)$$

This direction is obtained from the derivative of (6.27) which is assumed to be zero at the minimum of the quadratic model. The vector  $p_k$  points from the current position to the exact minimum of the quadratic model of the space. The rate of convergence is quadratic, being superior to both linear and superlinear convergence. The technique is computationally expensive due to the calculation of the Hessian. It is also susceptible to failure when optimisation commences from distant positions in the space as the Hessian may not be positive definite and hence not convex, a condition required for the search direction both to point downhill and to be reasonably oriented. In these cases the quadratic model is a poor description of the space.

A practical Newton algorithm which is robust for distant starting points is the Newton conjugate gradient method (Newton-CG). This line search method, which is also called the truncated Newton algorithm, finds an approximate solution to Equation (6.29) by using a conjugate gradient (CG) sub-algorithm. Retaining the performance of the pure Newton algorithm, the CG sub-algorithm guarantees that the search direction is always downhill as the method terminates when negative curvature is encountered. This algorithm is similar to the Newton-Raphson-CG algorithm implemented within Dasha. Newton optimisation is sometimes also known as the Newton-Raphson algorithm and, as documented in the source code, the Newton algorithm in Dasha is coupled to a conjugate gradient algorithm. The auxiliary step-length selection algorithm in Dasha is undocumented and may not be employed.

Once the search direction has been determined by the above algorithms the minimum along that direction needs to be determined. Not to be confused with the methodology for determining the search direction  $p_k$ , the line search itself is performed by an auxiliary step-length selection algorithm to find the value  $\alpha_k$ . A number of step-length selection methods can be used to find a minimum along the line  $\theta_k + \alpha_k p_k$ , although only two will be investigated. The first is the backtracking line search of Nocedal and Wright (1999). This method is inexact – it takes a starting step length  $\alpha_k$  and decreases the value until a sufficient decrease in the function is found. The second is the line search method of Moré and Thuente (1994). Designed to be robust, the MT algorithm finds the exact minimum along the search direction and guarantees sufficient decrease.

### Trust region methods

In the trust region class of algorithms the curvature of the space is modelled quadratically by (6.27). This model is assumed to be reliable only within a region of trust defined by the inequality  $\|p\| \leq \Delta_k$  where  $p$  is the step taken by the algorithm and  $\Delta_k$  is the radius of the  $n$ -dimensional sphere of trust (Nocedal and Wright, 1999). The solution sought for each iteration of the algorithm is

$$\min_{p \in \mathbb{R}^n} m_k(p) = f_k + p^T \nabla f_k + \frac{1}{2} p^T B_k p, \quad \text{s.t. } \|p\| \leq \Delta_k, \quad (6.30)$$

where  $m_k(p)$  is the quadratic model,  $B_k$  is a positive definite matrix which can be the true Hessian as in the Newton model or an approximation such as the BFGS matrix, and  $\|p\|$

is the Euclidean norm of  $p$ . The trust region radius  $\Delta_k$  is modified dynamically during optimisation – if the quadratic model is found to be a poor representation of the space the radius is decreased whereas if the quadratic model is found to be reasonable the radius is increased to allow larger, more efficient steps to be taken.

The Cauchy point algorithm is similar in concept to the steepest descent line search algorithm. The Cauchy point is the point lying on the gradient which minimises the quadratic model subject to the step being within the trust region. By iteratively finding the Cauchy point the local minimum can be found. The convergence of the technique is inefficient, being similar to that of the steepest descent algorithm.

In changing the trust region radius the exact solutions to (6.30) map out a curved trajectory which starts parallel to the gradient for small radii. The end of the trajectory, which occurs for radii greater than the step length, is the bottom of the quadratic model. The dogleg algorithm attempts to follow a similar path by first finding the minimum along the gradient and then finding the minimum along a trajectory from the current point to the bottom of the quadratic model. The minimum along the second path is either the trust region boundary or the quadratic solution. The matrix  $B_k$  of (6.30) can be the BFGS matrix, the unmodified Hessian, or a Hessian modified to be positive definite.

Another trust region algorithm is Steihaug's modified conjugate gradient approach (Steihaug, 1983). For each step  $k$  an iterative technique is used which is almost identical to the standard conjugate gradient procedure except for two additional termination conditions. The first is if the next step is outside the trust region, the second is if a direction of zero or negative curvature is encountered.

An almost exact solution to (6.30) can be found using an algorithm described in Nocedal and Wright (1999). This exact trust region algorithm aims to precisely find the minimum of the quadratic model  $m_k$  of the space within the trust region  $\Delta_k$ . Any matrix  $B_k$  can be used to construct the quadratic model. However, the technique is computationally expensive.

## Conjugate gradient methods

The conjugate gradient algorithm (CG) was originally designed as a mathematical technique for solving a large system of linear equations Hestenes and Stiefel (1952), but was later adapted to solving nonlinear optimisation problems (Fletcher and Reeves, 1964). The technique loops over a set of directions  $p_0, p_1, \dots, p_n$  which are all conjugate to the Hessian (Nocedal and Wright, 1999), a property defined as

$$p_i^T \nabla^2 f_k p_j = 0, \quad \text{for all } i \neq j. \quad (6.31)$$

By performing line searches over all directions  $p_j$  the solution to the quadratic model (6.27) of the position  $\theta_k$  will be found in  $n$  or less iterations of the CG algorithm where  $n$  is the total number of parameters in the model. The technique performs well on large problems with many parameters as no matrices are calculated or stored. The algorithms perform better than the steepest descent method and preconditioning of the system is used to improve optimisation. A number of preconditioned techniques will be investigated including the Fletcher-Reeves algorithm which was the original conjugate

gradient optimisation technique (Fletcher and Reeves, 1964), the Polak-Ribière method (Polak and Ribière, 1969), a modified Polak-Ribière method called the Polak-Ribière + method (Nocedal and Wright, 1999), and the Hestenes-Stiefel algorithm which originates from a formula in Hestenes and Stiefel (1952). As a line search is performed to find the minimum along each conjugate direction both the backtracking and Moré and Thuente auxiliary step-length selection algorithms will be tested with the CG algorithms.

### Hessian modifications

The Newton search direction, used in both the line search and trust region methods, is dependent on the Hessian being positive definite for the quadratic model to be convex so that the search direction points sufficiently downhill. This is not always the case as saddle points and other non-quadratic features of the space can be problematic. Two classes of algorithms can be used to handle this situation. The first involves using the conjugate gradient method as a sub-algorithm for solving the Newton problem for the step  $k$ . The Newton-CG line search algorithm described above is one such example. The second class involves modifying the Hessian prior to, or at the same time as, finding the Newton step to guarantee that the replacement matrix  $B_k$  is positive definite. The convexity of  $B_k$  is ensured by its eigenvalues all being positive. The performance of two of these methods within the model-free space will be investigated.

The first modification uses the Cholesky factorisation of the matrix  $B_k$ , initialised to the true Hessian, to test for convexity (Algorithm 6.3 of Nocedal and Wright (1999)). If factorisation fails the matrix is not positive definite and a constant  $\tau_k$  times the identity matrix  $I$  is then added to  $B_k$ . The constant originates from the Robbins norm of the Hessian  $\|\nabla^2 f_k\|_F$  and is steadily increased until the factorisation is successful. The resultant Cholesky lower triangular matrix  $L$  can then be used to find the approximate Newton direction. If  $\tau_k$  is too large the convergence of this technique can approach that of the steepest descent algorithm.

The second method is the Gill, Murray, and Wright (GMW) algorithm (Gill et al., 1981) which modifies the Hessian during the execution of the Cholesky factorisation  $\nabla^2 f_k = LIL^T$ , where  $L$  is a lower triangular matrix and  $D$  is a diagonal matrix. Only a single factorisation is required. As rows and columns are interchanged during the algorithm the technique may be slow for large problems such as the optimisation of the model-free parameters of all residues together with the diffusion tensor parameters. The rate of convergence of the technique is quadratic.

### Other methods

Two other optimisation algorithms which cannot be classified within line search, trust region, or conjugate gradient categories will also be investigated. The first is the well known simplex optimisation algorithm. The technique is often used as the only the function value is employed and hence the derivation of the gradient and Hessian can be avoided. The simplex is created as an  $n$ -dimensional geometric object with  $n + 1$  vertices. The first vertex is the starting position. Each of the other  $n$  vertices are created by shifting the starting position by a small amount parallel to one of unit vectors defining the coordinate system of the space. Four simple rules are used to move the simplex through the space:



reflection, extension, contraction, and a shrinkage of the entire simplex. The result of these movements is that the simplex moves in an ameoboid-like fashion downhill, shrinking to pass through tight gaps and expanding to quickly move through non-convoluted space, eventually finding the minimum.

Key to these four movements is the pivot point, the centre of the face created by the  $n$  vertices with the lowest function values. The first movement is a reflection – the vertex with the greatest function value is reflected through the pivot point on the opposite face of the simplex. If the function value at this new position is less than all others the simplex is allowed to extend – the point is moved along the line to twice the distance between the current position and the pivot point. Otherwise if the function value is greater than the second highest value but less than the highest value, the reflected simplex is contracted. The reflected point is moved to be closer to the simplex, its position being half way between the reflected position and the pivot point. Otherwise if the function value at the reflected point is greater than all other vertices, then the original simplex is contracted – the highest vertex is moved to a position half way between the current position and the pivot point. Finally if none of these four movements yield an improvement, then the simplex is shrunk halfway towards the vertex with the lowest function value.

The other algorithm is the commonly used Levenberg-Marquardt algorithm ([Levenberg, 1944](#); [Marquardt, 1963](#)) which is implemented in Modelfree4, Dasha, and Tensor2. This technique is designed for least-squares problems to which the chi-squared equation (6.25) belongs. The key to the algorithm is the replacement of the Hessian with the Levenberg-Marquardt matrix  $J^T J + \lambda I$ , where  $J$  is the Jacobian of the system calculated as the matrix of partial derivatives of the residuals,  $\lambda > 0$  is a factor related to the trust-region radius, and  $I$  is the identity matrix. The algorithm is conceptually allied to the trust region methods and its performance varies finely between that of the steepest descent and the pure Newton step. When far from the minimum  $\lambda$  is large and the algorithm takes steps close to the gradient; when in vicinity of the minimum  $\lambda$  heads towards zero and the steps taken approximate the Newton direction. Hence the algorithm avoids the problems of the Newton algorithm when non-convex curvature is encountered and approximates the Newton step in convex regions of the space.

### Constraint algorithms

To guarantee that the minimum will still be reached the implementation of constraints limiting the parameter values together with optimisation algorithms is not a triviality. For this to occur the space and its boundaries must remain smooth thereby allowing the algorithm to move along the boundary to either find the minimum along the limit or to slide along the limit and then move back into the centre of the constrained space once the curvature allows it. One of the most powerful approaches is the Method of Multipliers ([Nocedal and Wright, 1999](#)), also known as the Augmented Lagrangian. Instead of a single optimisation the algorithm is iterative with each iteration consisting of an independent unconstrained minimisation on a sequentially modified space. When inside the limits the function value is unchanged but when outside a penalty, which is proportional to the distance outside the limit, is added to the function value. This penalty, which is based on the Lagrange multipliers, is smooth and hence the gradient and Hessian are continuous at and beyond the constraints. For each iteration of the Method of Multipliers the penalty is increased until it becomes impossible for the parameter vector to be in violation of the



limits. This approach allows the parameter vector  $\theta$  outside the limits yet the successive iterations ensure that the final results will not be in violation of the constraint.

For inequality constraints, each iteration of the Method of Multipliers attempts to solve the quadratic sub-problem

$$\min_{\theta} \mathcal{L}_A(\theta, \lambda^k; \mu_k) \stackrel{\text{def}}{=} f(\theta) + \sum_{i \in \mathcal{I}} \Psi(c_i(\theta), \lambda_i^k; \mu_k), \quad (6.32)$$

where the function  $\Psi$  is defined as

$$\Psi(c_i(\theta), \lambda_i^k; \mu_k) = \begin{cases} -\lambda_i^k c_i(\theta) + \frac{1}{2\mu_k} c_i^2(\theta) & \text{if } c_i(\theta) - \mu_k \lambda_i^k \leq 0, \\ -\frac{\mu_k}{2} (\lambda_i^k)^2 & \text{otherwise.} \end{cases} \quad (6.33)$$

In (6.32),  $\theta$  is the parameter vector;  $\mathcal{L}_A$  is the Augmented Lagrangian function;  $k$  is the current iteration of the Method of Multipliers;  $\lambda^k$  are the Lagrange multipliers which are positive factors such that, at the minimum  $\hat{\theta}$ ,  $\nabla f(\hat{\theta}) = \lambda_i \nabla c_i(\hat{\theta})$ ;  $\mu_k > 0$  is the penalty parameter which decreases to zero as  $k \rightarrow \infty$ ;  $\mathcal{I}$  is the set of inequality constraints; and  $c_i(\theta)$  is an individual constraint value. The Lagrange multipliers are updated using the formula

$$\lambda_i^{k+1} = \max(\lambda_i^k - c_i(\theta)/\mu_k, 0), \quad \text{for all } i \in \mathcal{I}. \quad (6.34)$$

The gradient of the Augmented Lagrangian is

$$\nabla \mathcal{L}_A(\theta, \lambda^k; \mu_k) = \nabla f(\theta) - \sum_{i \in \mathcal{I} | c_i(\theta) \leq \mu_k \lambda_i^k} \left( \lambda_i^k - \frac{c_i(\theta)}{\mu_k} \right) \nabla c_i(\theta), \quad (6.35)$$

and the Hessian is

$$\nabla^2 \mathcal{L}_A(\theta, \lambda^k; \mu_k) = \nabla^2 f(\theta) + \sum_{i \in \mathcal{I} | c_i(\theta) \leq \mu_k \lambda_i^k} \left[ \frac{1}{\mu_k} \nabla c_i^2(\theta) - \left( \lambda_i^k - \frac{c_i(\theta)}{\mu_k} \right) \nabla^2 c_i(\theta) \right]. \quad (6.36)$$

The Augmented Lagrangian algorithm can accept any set of three arbitrary constraint functions  $c(\theta)$ ,  $\nabla c(\theta)$ , and  $\nabla^2 c(\theta)$ . When given the current parameter values  $c(\theta)$  returns a vector of constraint values whereby each position corresponds to one of the model parameters. The constraint is defined as  $c_i \geq 0$ . The function  $\nabla c(\theta)$  returns the matrix of constraint gradients and  $\nabla^2 c(\theta)$  is the constraint Hessian function which should return the 3D matrix of constraint Hessians.

A more specific set of constraints accepted by the Method of Multipliers are bound constraints. These are defined by the function

$$l \leq \theta \leq u, \quad (6.37)$$

where  $l$  and  $u$  are the vectors of lower and upper bounds respectively and  $\theta$  is the parameter vector. For example for model-free model  $m4$  to place lower and upper bounds on the order

parameter and lower bounds on the correlation time and chemical exchange parameters, the vectors are

$$\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \leq \begin{pmatrix} S^2 \\ \tau_e \\ R_{ex} \end{pmatrix} \leq \begin{pmatrix} 1 \\ \infty \\ \infty \end{pmatrix}. \quad (6.38)$$

The default setting in the program relax is to use linear constraints which are defined as

$$A \cdot \theta \geq b, \quad (6.39)$$

where  $A$  is an  $m \times n$  matrix where the rows are the transposed vectors  $a_i$  of length  $n$ ; the elements of  $a_i$  are the coefficients of the model parameters;  $\theta$  is the vector of model parameters of dimension  $n$ ;  $b$  is the vector of scalars of dimension  $m$ ;  $m$  is the number of constraints; and  $n$  is the number of model parameters. For model-free analysis, linear constraints are the most useful type of constraint as the correlation time  $\tau_f$  can be restricted to being less than  $\tau_s$  by using the inequality  $\tau_s - \tau_f \geq 0$ .

In rearranging (6.39) the linear constraint function  $c(\theta)$  returns the vector  $A \cdot \theta - b$ . Because of the linearity of the constraints the gradient and Hessian are greatly simplified. The gradient  $\nabla c(\theta)$  is simply the matrix  $A$  and the Hessian  $\nabla^2 c(\theta)$  is zero. For the parameters specific to individual residues the linear constraints in the notation of (6.39) are

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} S^2 \\ S_f^2 \\ S_s^2 \\ \tau_e \\ \tau_f \\ \tau_s \\ R_{ex} \\ r \\ CSA \end{pmatrix} \geq \begin{pmatrix} 0 \\ -1 \\ 0 \\ -1 \\ 0 \\ -1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.9e^{-10} \\ 2e^{-10} \\ 300e^{-6} \\ 0 \end{pmatrix}. \quad (6.40)$$

Through the isolation of each individual element, the constraints can be seen to be equivalent

to

$$0 \leq S^2 \leq 1, \quad (6.41a)$$

$$0 \leq S_f^2 \leq 1, \quad (6.41b)$$

$$0 \leq S_s^2 \leq 1, \quad (6.41c)$$

$$S^2 \leq S_f^2, \quad (6.41d)$$

$$S^2 \leq S_s^2, \quad (6.41e)$$

$$\tau_e \geq 0, \quad (6.41f)$$

$$\tau_f \geq 0, \quad (6.41g)$$

$$\tau_s \geq 0, \quad (6.41h)$$

$$\tau_s \geq 0, \quad (6.41i)$$

$$\tau_f \leq \tau_s, \quad (6.41j)$$

$$R_{ex} \geq 0, \quad (6.41k)$$

$$0.9e^{-10} \leq r \leq 2e^{-10}, \quad (6.41l)$$

$$-300e^{-6} \leq CSA \leq 0. \quad (6.41m)$$

To prevent the computationally expensive optimisation of failed models in which the internal correlation times minimise to infinity (d'Auvergne and Gooley, 2006), the constraint  $\tau_e, \tau_f, \tau_s \leq 2\tau_m$  was implemented. When the global correlation time is fixed the constraints in the matrix notation of (6.39) are

$$\begin{pmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} \tau_e \\ \tau_f \\ \tau_s \end{pmatrix} \geq \begin{pmatrix} -2\tau_m \\ -2\tau_m \\ -2\tau_m \end{pmatrix}. \quad (6.42)$$

However when the global correlation time  $\tau_m$  is one of the parameters being optimised the constraints become

$$\begin{pmatrix} 2 & -1 & 0 & 0 \\ 2 & 0 & -1 & 0 \\ 2 & 0 & 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} \tau_m \\ \tau_e \\ \tau_f \\ \tau_s \end{pmatrix} \geq \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}. \quad (6.43)$$

For the parameters of the diffusion tensor the constraints utilised are

$$0 \leq \tau_m \leq 200.0e^{-9}, \quad (6.44a)$$

$$\mathfrak{D}_a \geq 0, \quad (6.44b)$$

$$0 \leq \mathfrak{D}_r \leq 1, \quad (6.44c)$$

which in the matrix notation of (6.39) become

$$\begin{pmatrix} 1 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} \tau_m \\ \mathfrak{D}_a \\ \mathfrak{D}_r \end{pmatrix} \geq \begin{pmatrix} 0 \\ -200.0e^{-9} \\ 0 \\ 0 \\ -1 \end{pmatrix}. \quad (6.45)$$



For the ellipsoidal diffusion parameters  $\{\tau_m, \mathfrak{D}_a, \mathfrak{D}_r, \alpha, \beta, \gamma\}$  the scaling matrix is

$$\begin{pmatrix} 1e^{-12} & 0 & 0 & 0 & 0 & 0 \\ 0 & 1e^7 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}. \quad (6.49)$$

For the spheroidal diffusion parameters  $\{\tau_m, \mathfrak{D}_a, \theta, \phi\}$  the scaling matrix is

$$\begin{pmatrix} 1e^{-12} & 0 & 0 & 0 \\ 0 & 1e^7 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \quad (6.50)$$

## 6.2 Optimisation of a single model-free model

### 6.2.1 The sample script

The sample script which demonstrates the optimisation of model-free model *m4* which consists of the parameters  $\{S^2, \tau_e, R_{ex}\}$  is ‘model-free.py’. The text of the script is:

```
# Script for model-free analysis.

# Create the data pipe.
name = 'm4'
pipe.create(name, 'mf')

# Load the sequence.
sequence.read('noe.500.out')

# Load the relaxation data.
relax_data.read('R1', '600', 600.0 * 1e6, 'r1.600.out')
relax_data.read('R2', '600', 600.0 * 1e6, 'r2.600.out')
relax_data.read('NOE', '600', 600.0 * 1e6, 'noe.600.out')
relax_data.read('R1', '500', 500.0 * 1e6, 'r1.500.out')
relax_data.read('R2', '500', 500.0 * 1e6, 'r2.500.out')
relax_data.read('NOE', '500', 500.0 * 1e6, 'noe.500.out')

# Setup other values.
diffusion_tensor.init(10e-9, fixed=True)
value.set(1.02 * 1e-10, 'bond_length')
value.set(-160 * 1e-6, 'csa')
value.set('15N', 'heteronucleus')
value.set('1H', 'proton')

# Select the model-free model.
```

```

model_free.select_model(model=name)

# Grid search.
grid_search(inc=11)

# Minimise.
minimise('newton')

# Monte Carlo simulations.
monte_carlo.setup(number=100)
monte_carlo.create_data()
monte_carlo.initial_values()
minimise('newton')
eliminate()
monte_carlo.error_analysis()

# Finish.
results.write(file='results', force=True)
state.save('save', force=True)

```

### 6.2.2 The rest

*Please write me!*

Until this section is completed please look at the sample script 'model-free.py'.

## 6.3 Optimisation of all model-free models

### 6.3.1 The sample script

The sample script which demonstrates the optimisation of all model-free models from  $m0$  to  $m9$  of individual residues is 'mf\_multimodel.py'. The important parts of the script are:

```

# Set the data pipe names (also the names of preset model-free models).
pipes = ['m0', 'm1', 'm2', 'm3', 'm4', 'm5', 'm6', 'm7', 'm8', 'm9']

# Loop over the pipes.
for name in pipes:
    # Create the data pipe.
    pipe.create(name, 'mf')

    # Load the sequence.
    sequence.read('noe.500.out')

    # Load the relaxation data.
    relax_data.read('R1', '600', 600.0 * 1e6, 'r1.600.out')

```

```

relax_data.read('R2', '600', 600.0 * 1e6, 'r2.600.out')
relax_data.read('NOE', '600', 600.0 * 1e6, 'noe.600.out')
relax_data.read('R1', '500', 500.0 * 1e6, 'r1.500.out')
relax_data.read('R2', '500', 500.0 * 1e6, 'r2.500.out')
relax_data.read('NOE', '500', 500.0 * 1e6, 'noe.500.out')

# Setup other values.
diffusion_tensor.init(1e-8, fixed=True)
value.set(1.02 * 1e-10, 'bond_length')
value.set(-160 * 1e-6, 'csa')
value.set('15N', 'heteronucleus')
value.set('1H', 'proton')

# Select the model-free model.
model_free.select_model(model=name)

# Minimise.
grid_search(inc=11)
minimise('newton')

# Write the results.
results.write(file='results', force=True)

# Save the program state.
state.save('save', force=True)

```

### 6.3.2 The rest

*Please write me!*

Until this section is completed please look at the sample script 'mf\_multimodel.py'.

## 6.4 Model-free model selection

### 6.4.1 The sample script

The sample script which demonstrates both model-free model elimination and model-free model selection between models from  $m_0$  to  $m_9$  is 'modsel.py'. The text of the script is:

```

# Set the data pipe names.
pipes = ['m0', 'm1', 'm2', 'm3', 'm4', 'm5', 'm6', 'm7', 'm8', 'm9']

# Loop over the data pipe names.
for name in pipes:
    print '\n\n# ' + name + ' #'

# Create the data pipe.

```

```

pipe.create(name, 'mf')

# Reload precalculated results from the file 'm1/results', etc.
results.read(file='results', dir=name)

# Model elimination.
eliminate()

# Model selection.
model_selection(method='AIC', modsel_pipe='aic')

# Write the results.
state.save('save', force=True)
results.write(file='results', force=True)

```

### 6.4.2 The rest

*Please write me!*

Until this section is completed please look at the sample script 'modsel.py'.

## 6.5 The methodology of Mandel et al., 1995

By presenting a systematic methodology for obtaining a consistent model-free description of the dynamics of the system, the manuscript of [Mandel et al. \(1995\)](#) revolutionised the application of model-free analysis. The full protocol is presented in Figure 6.1.

All of the data analysis techniques required for this protocol can be implemented within relax. The chi-squared distributions required for the chi-squared tests are constructed by Modelfree4 from the Monte Carlo simulations. If the optimisation algorithms and Monte Carlo simulations built into relax are utilised, then the relax script will need to construct the chi-squared distributions from the results as this is not yet coded into relax. The specific step-up hypothesis testing model selection of [Mandel et al. \(1995\)](#) is available through the `model_selection()` user function. Coding the rest of the protocol into a script should be straightforward.

## 6.6 The diffusion seeded paradigm

Ever since the original Lipari and Szabo papers ([Lipari and Szabo, 1982a,b](#)), the question of how to obtain the model-free description of the system has followed the route in which the diffusion tensor is initially estimated. Using this rough estimate, the model-free models are optimised for each spin system  $i$ , the best model selected, and then the global model  $\mathfrak{S}$  of the diffusion model  $\mathfrak{D}$  with each model-free model  $\mathfrak{F}_i$  is optimised. This procedure is then repeated using the diffusion tensor parameters of  $\mathfrak{S}$  as the initial input. Finally the global model is selected. The full protocol is illustrated in Figure 6.2.



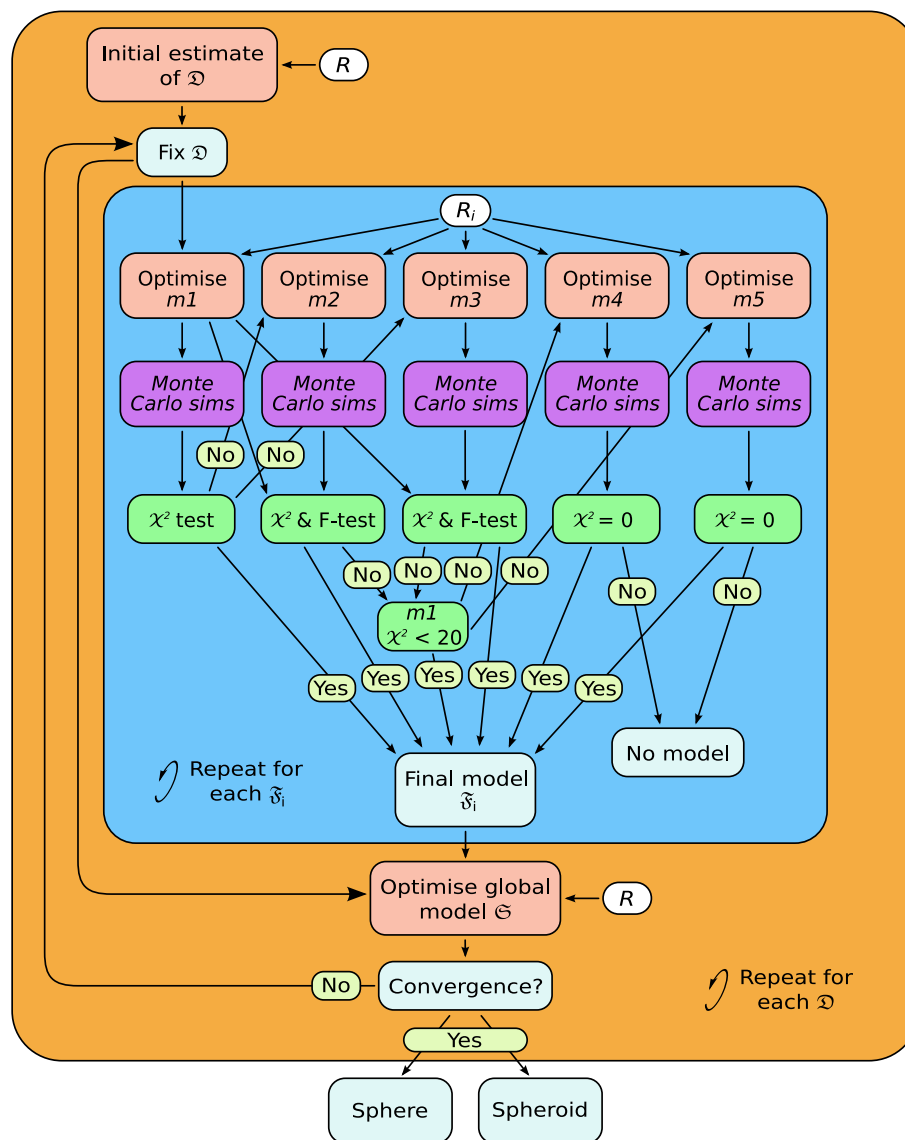


Figure 6.1: A schematic of the model-free optimisation protocol of Mandel et al. (1995). This specific protocol is for single field strength data. The initial diffusion tensor estimate is calculated using the  $R_2/R_1$  ratio. The diffusion parameters of  $\mathcal{D}$  are held constant while model-free models  $m1$  to  $m5$  (6.22.1–6.22.5) of the set  $\mathfrak{F}_i$  for each residue  $i$  are optimised and 500 Monte Carlo simulations executed. Using a web of ANOVA statistical tests, specifically  $\chi^2$  and F-tests, a step-up hypothesis testing model selection procedure is used to choose the best model-free model. These steps are repeated for all residues of the protein. The global model  $\mathfrak{S}$ , the union of  $\mathcal{D}$  and all  $\mathfrak{F}_i$ , is then optimised. These steps are repeated until convergence of the global model. The iterative process is repeated for both isotropic diffusion (sphere) and anisotropic diffusion (spheroid).

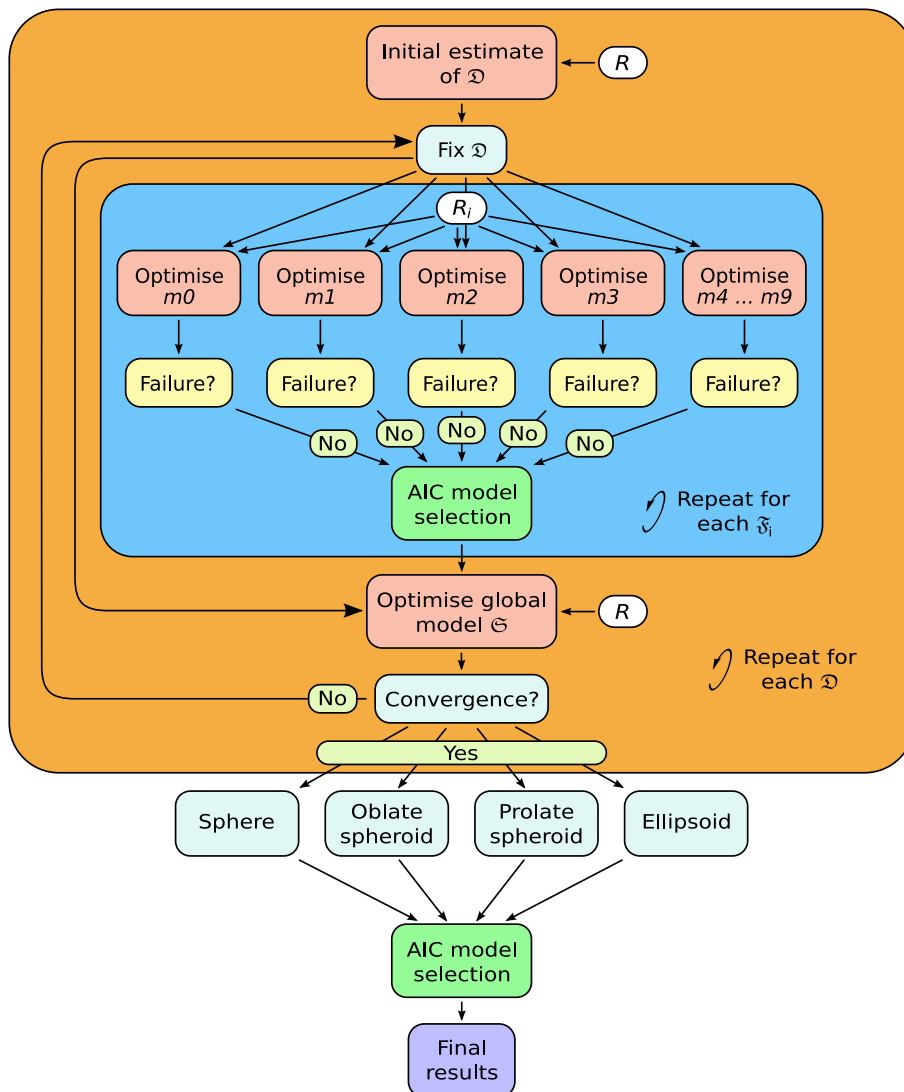


Figure 6.2: A schematic of model-free analysis using the diffusion seeded paradigm – the initial diffusion tensor estimate – together with AIC model selection and model elimination. The initial estimates of the parameters of  $\mathcal{D}$  are held constant while model-free models  $m_0$  to  $m_9$  (6.22.0–6.22.9) of the set  $\mathfrak{F}_i$  for each spin system  $i$  are optimised, model elimination applied to remove failed models, and AIC model selection used to determine the best model. The global model  $\mathfrak{S}$ , the union of  $\mathcal{D}$  and all  $\mathfrak{F}_i$ , is then optimised. These steps are repeated until convergence of the global model. The entire iterative process is repeated for each of the Brownian diffusion models. Finally AIC model selection is used to determine the best description of the dynamics of the molecule by selecting between the global models  $\mathfrak{S}$  including the sphere, oblate spheroid, prolate spheroid, and ellipsoid. Once the solution has been found, Monte Carlo simulations can be utilised for error analysis.

## 6.7 The new model-free optimisation protocol

*Please write me!*

Until this section is written please look at the sample script ‘`full_analysis.py`’. A description of the protocol is given at the top of the script. The protocol is summarised in Figure [6.3](#).

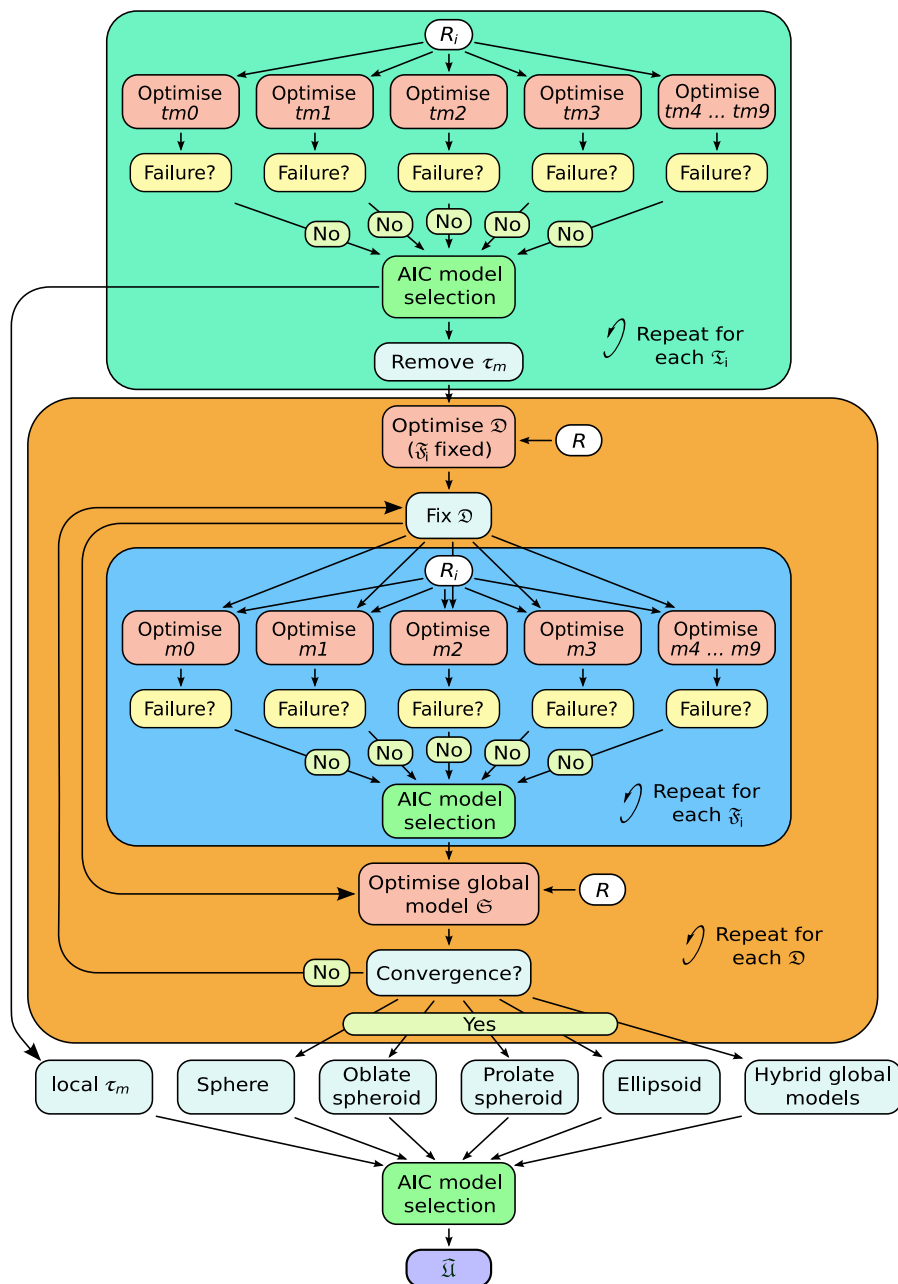


Figure 6.3: A schematic of the new model-free optimisation protocol. Initially models  $tm_0$  to  $tm_9$  (6.23.0–6.23.9) of the set  $\mathfrak{T}_i$  for each spin system  $i$  are optimised, model elimination used to remove failed models, and AIC model selection used to pick the best model. Once all the  $\mathfrak{T}_i$  have been determined for the system the the local  $\tau_m$  parameter is removed, the model-free parameters are held fixed, and the global diffusion parameters of  $\mathfrak{D}$  are optimised. These parameters are used as input for the central part of the schematic which follows the same procedure as that of Figure 6.2. Convergence is however precisely defined as identical models  $\mathfrak{S}$ , identical  $\chi^2$  values, and identical parameters  $\theta$  between two iterations. The universal solution  $\hat{\mathfrak{U}}$ , the best description of the dynamics of the molecule, is determined using AIC model selection to select between the local  $\tau_m$  models for all spins, the sphere, oblate spheroid, prolate spheroid, ellipsoid, and possibly hybrid models whereby multiple diffusion tensors have been applied to different parts of the molecule.

## Chapter 7

# Reduced spectral density mapping

*Please write me!*

Until this chapter is written please look at the sample script ‘`jw_mapping.py`’.



## Chapter 8

# Values, gradients, and Hessians

### 8.1 Introduction

A word of warning before reading this chapter, the topics covered here are quite advanced and are not necessary for understanding how to either use relax or to implement any of the data analysis techniques present within relax. The material of this chapter is intended as an in-depth explanation of the mathematics involved in the optimisation of the parameters of the model-free models. As such it contains the chi-squared equation, relaxation equations, spectral density functions, and diffusion tensor equations as well as their gradients (the vector of first partial derivatives) and Hessians (the matrix of second partial derivatives). All these equations are used in the optimisation of models *m0* to *m9*; models *tm0* to *tm9*; the ellipsoidal, spheroidal, and spherical diffusion tensors; and the combination of the diffusion tensor and the model-free models.

### 8.2 Minimisation concepts

#### 8.2.1 The function value

At the simplest level all minimisation techniques require at least a function which will supply a single value for different parameter values  $\theta$ . For the modelling of NMR relaxation data this function is the chi-squared equation (6.1) on page 33. For certain algorithms, such a simplex minimisation, this single value suffices.

#### 8.2.2 The gradient

The majority of minimisation algorithms also require the gradient at the point in the space represented by the parameter values  $\theta$ . The gradient is a vector of partial derivatives and

is defined as

$$\nabla = \begin{pmatrix} \frac{\partial}{\partial \theta_1} \\ \frac{\partial}{\partial \theta_2} \\ \vdots \\ \frac{\partial}{\partial \theta_n} \end{pmatrix} \quad (8.1)$$

where  $n$  is the total number of parameters in the model.

An example of a powerful algorithm which requires both the value and gradient at current parameter values is the BFGS quasi-Newton minimisation. The gradient is also essential for the use of the Method of Multipliers constraints algorithm (also known as the Augmented Lagrangian algorithm).

### 8.2.3 The Hessian

A few optimisation algorithms, which are among the most reliable for model-free analysis, additionally require the Hessian at current parameter values  $\theta$ . The Hessian is the matrix of second partial derivatives and is defined as

$$\nabla^2 = \begin{pmatrix} \frac{\partial^2}{\partial \theta_1^2} & \frac{\partial^2}{\partial \theta_1 \partial \theta_2} & \cdots & \frac{\partial^2}{\partial \theta_1 \partial \theta_n} \\ \frac{\partial^2}{\partial \theta_2 \partial \theta_1} & \frac{\partial^2}{\partial \theta_2^2} & \cdots & \frac{\partial^2}{\partial \theta_2 \partial \theta_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2}{\partial \theta_n \partial \theta_1} & \frac{\partial^2}{\partial \theta_n \partial \theta_2} & \cdots & \frac{\partial^2}{\partial \theta_n^2} \end{pmatrix}. \quad (8.2)$$

As the order in which the partial derivatives are calculated is inconsequential the Hessian is symmetric.

The most powerful minimisation algorithm for model-free analysis – Newton optimisation – requires the value, gradient, and Hessian at the current parameter values.

## 8.3 The four parameter combinations

In model-free analysis four different combinations of parameters can be optimised, each of which requires a different approach to the construction of the chi-squared value, gradient, and Hessian. These categories depend on whether the model-free parameter set  $\mathfrak{F}$ , the diffusion tensor parameter set  $\mathfrak{D}$ , or both sets are simultaneously optimised. The addition of the local  $\tau_m$  parameter to the model-free set  $\mathfrak{F}$  creates a fourth parameter combination.

### 8.3.1 Optimisation of the model-free models

This is the simplest category as it involves solely the optimisation of the model-free parameters of an individual residue while the diffusion tensor parameters are held constant. The model-free parameters belong to the set  $\mathfrak{F}_i$  of the residue  $i$ . The models include  $m0$  to  $m9$  and the dimensionality is low with

$$\dim \mathfrak{F}_i = k \leq 5 \quad (8.3)$$



for the most complex model  $m8 = \{S^2, \tau_f, S_f^2, \tau_s, R_{ex}\}$ . The relaxation data of a single residue is used to build the chi-squared value, gradient, and Hessian.

### 8.3.2 Optimisation of the local $\tau_m$ models

The addition of the local  $\tau_m$  parameter to the set  $\mathfrak{F}_i$  creates a new set of models which will be labelled  $\mathfrak{T}_i$ . These include models  $tm0$  to  $tm9$ . The local  $\tau_m$  parameter is the single member of the set  $\mathfrak{D}_i$  and in set notation

$$\mathfrak{T}_i = \mathfrak{D}_i \cup \mathfrak{F}_i. \quad (8.4)$$

Although the Brownian rotational diffusion parameter local  $\tau_m$  is optimised, this category is residue specific. As such the complexity of the optimisation is lower than the next two categories. It is slightly greater than the optimisation of the set  $\mathfrak{F}_i$  as

$$\dim \mathfrak{T}_i = 1 + k \leq 6, \quad (8.5)$$

where  $k$  is the number of model-free parameters.

### 8.3.3 Optimisation of the diffusion tensor parameters

The parameters of the Brownian rotational diffusion tensor belong to the set  $\mathfrak{D}$ . This set is the union of the geometric parameters  $\mathfrak{G} = \{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r\}$  and the orientational parameters  $\mathfrak{O}$ ,

$$\mathfrak{D} = \mathfrak{G} \cup \mathfrak{O}. \quad (8.6)$$

When diffusion is spherical solely the geometric parameter  $\mathfrak{D}_{iso}$  is optimised. When the molecule diffuses as a spheroid the geometric parameters  $\mathfrak{D}_{iso}$  and  $\mathfrak{D}_a$  and the orientational parameters  $\theta$  (the polar angle) and  $\phi$  (the azimuthal angle) are optimised. If the molecule diffuses as an ellipsoid the geometric parameters  $\mathfrak{D}_{iso}$ ,  $\mathfrak{D}_a$ , and  $\mathfrak{D}_r$  are optimised together with the Euler angles  $\alpha$ ,  $\beta$ , and  $\gamma$ .

This category is defined as the optimisation of solely the parameters of  $\mathfrak{D}$ . The model-free parameters of  $\mathfrak{F}$  are held constant. As all selected residues of the macromolecule are involved in the optimisation, this category is global and can be more complex than the optimisation of  $\mathfrak{F}_i$  or  $\mathfrak{T}_i$ . The dimensionality of the problem nevertheless low with

$$\dim \mathfrak{D} = 1, \quad \dim \mathfrak{D} = 4, \quad \dim \mathfrak{D} = 6, \quad (8.7)$$

for the diffusion as a sphere, spheroid, and ellipsoid respectively.

### 8.3.4 Optimisation of the global model $\mathfrak{S}$

The global model is defined as

$$\mathfrak{S} = \mathfrak{D} \cup \left( \bigcup_{i=1}^l \mathfrak{F}_i \right), \quad (8.8)$$

where  $i$  is the residue index and  $l$  is the total number of residues used in the analysis. This is the most complex of the four categories as both diffusion tensor parameters and model-free parameters of all selected residues are optimised simultaneously. The dimensionality of the model  $\mathfrak{S}$  is much greater than the other categories and is equal to

$$\dim \mathfrak{S} = \dim \mathfrak{D} + \sum_{i=1}^l k_i \leq 6 + 5l, \quad (8.9)$$

where  $k_i$  is the number of model-free parameters for the residue  $i$  and is equal to  $\dim \mathfrak{F}_i$ , the number six corresponds to the maximum dimensionality of  $\mathfrak{D}$ , and the number five corresponds to the maximum dimensionality of  $\mathfrak{F}_i$ .

## 8.4 Construction of the values, gradients, and Hessians

### 8.4.1 The sum of chi-squared values

For the single residue models of  $\mathfrak{F}_i$  and  $\mathfrak{T}_i$  the chi-squared value  $\chi_i^2$  which is optimised is simply Equation (8.15) on page 64 in which the relaxation data is that of residue  $i$ . However for the global models  $\mathfrak{D}$  and  $\mathfrak{S}$  in which all selected residues are involved the optimised chi-squared value is the sum of those for each residue,

$$\chi^2 = \sum_{i=1}^l \chi_i^2, \quad (8.10)$$

where  $i$  is the residue index and  $l$  is the total number of residues used in the analysis. This is equivalent to Equation (8.15) when the index  $i$  ranges over the relaxation data of all selected residues.

### 8.4.2 Construction of the gradient

The construction of the gradient is significantly different for the models  $\mathfrak{F}_i$ ,  $\mathfrak{T}_i$ ,  $\mathfrak{D}$ , and  $\mathfrak{S}$ . In Figure 8.1 the construction of the chi-squared gradient  $\nabla \chi^2$  for the global model  $\mathfrak{S}$  is demonstrated. In this case

$$\nabla \chi^2 = \sum_{i=1}^l \nabla \chi_i^2, \quad (8.11)$$

where  $\nabla \chi_i^2$  is the vector of partial derivatives of the chi-squared equation  $\chi_i^2$  for the residue  $i$ . The length of this vector is

$$\|\nabla \chi_i^2\| = \dim \mathfrak{S}, \quad (8.12)$$

with each position of the vector  $j$  equal to  $\frac{\partial \chi_i^2}{\partial \theta_j}$  where each  $\theta_j$  is a parameter of the model.

The construction of the gradient  $\nabla \chi^2$  for the model  $\mathfrak{D}$  is simply a subset of that of  $\mathfrak{S}$ . This is demonstrated in Figure 8.1 by simply taking the component of the gradient  $\nabla \chi_i^2$

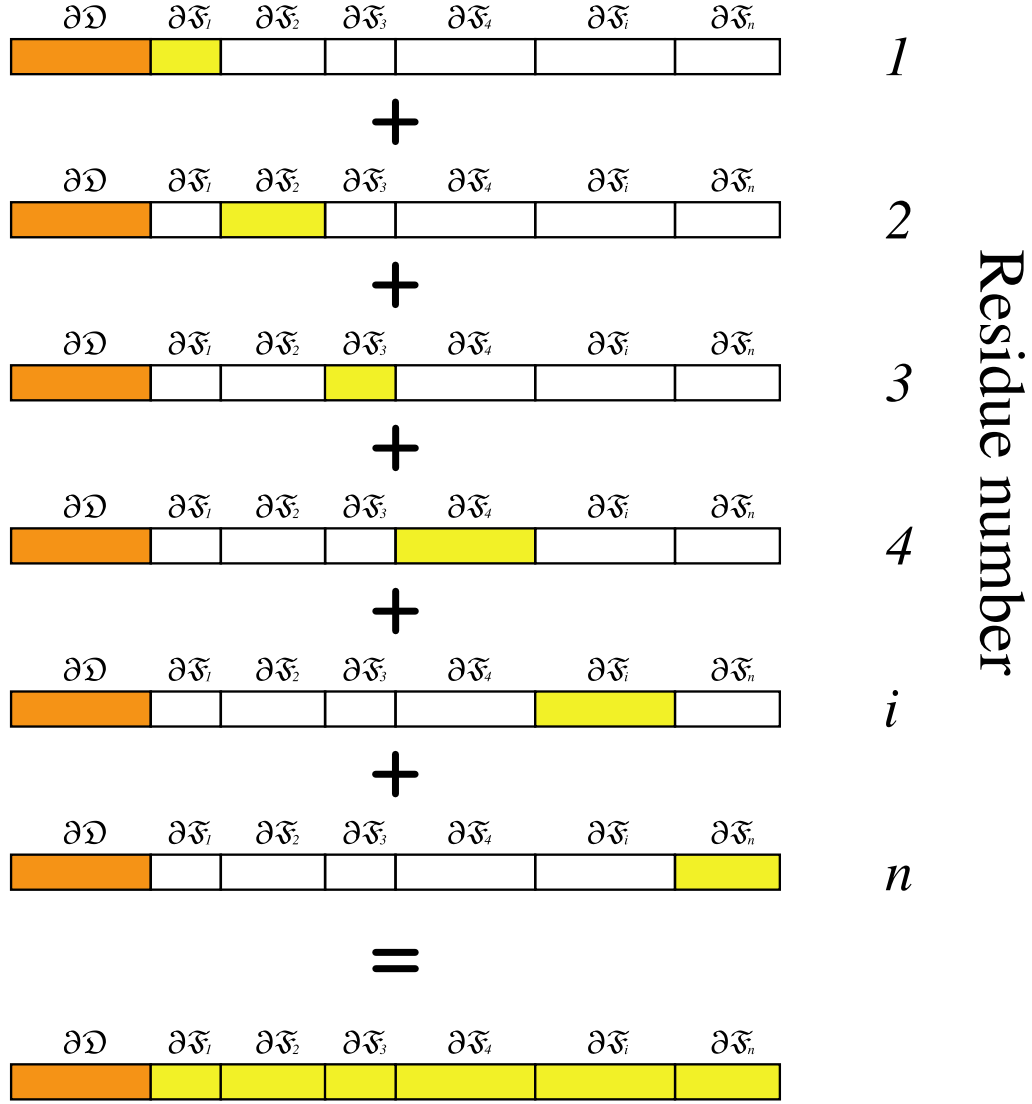


Figure 8.1: The construction of the model-free gradient  $\nabla \chi^2$  for the global model  $\mathfrak{S}$ . For each residue  $i$  a different vector  $\nabla \chi_i^2$  is constructed. The first element of the vector represented by the symbol  $\partial \mathfrak{D}$  (the orange block) is the sub-vector of chi-squared partial derivatives with respect to each of the diffusion tensor parameters  $\mathfrak{D}_j$ . The rest of the elements, grouped into blocks for each residue denoted by the symbol  $\partial \mathfrak{S}_i$ , are the sub-vectors of chi-squared partial derivatives with respect to each of the model-free parameters  $\mathfrak{S}_i^j$ . For the residue dependent vector  $\nabla \chi_i^2$  the partial derivatives with respect to the model-free parameters of  $\mathfrak{S}_j$  where  $i \neq j$  are zero. These blocks are left uncoloured. The complete gradient of  $\mathfrak{S}$  is the sum of the vectors  $\nabla \chi_i^2$ .

denoted by the symbol  $\partial\mathfrak{D}$  (the orange blocks) and summing these for all residues. This sum is given by (8.11) and

$$\|\nabla\chi_i^2\| = \dim \mathfrak{D}. \quad (8.13)$$

For the parameter set  $\mathfrak{T}_i$ , which consists of the local  $\tau_m$  parameter and the model-free parameters of a single residue, the gradient  $\nabla\chi_i^2$  for the residue  $i$  is simply the combination of the single orange block and single yellow block of the index  $i$  (Figure 8.1).

The model-free parameter set  $\mathfrak{F}_i$  is even simpler. In Figure 8.1 the gradient  $\nabla\chi_i^2$  is simply the vector denoted by the single yellow block for the residue  $i$ .

### 8.4.3 Construction of the Hessian

The construction of the Hessian for the models  $\mathfrak{F}_i$ ,  $\mathfrak{T}_i$ ,  $\mathfrak{D}$ , and  $\mathfrak{S}$  is very similar to the procedure used for the gradient. The chi-squared Hessian for the global models  $\mathfrak{D}$  and  $\mathfrak{S}$  is

$$\nabla^2\chi^2 = \sum_{i=1}^l \nabla^2\chi_i^2. \quad (8.14)$$

Figure 8.2 demonstrates the construction of the full Hessian for the model  $\mathfrak{S}$ . The Hessian for the model  $\mathfrak{D}$  is the sum of all the red blocks. The Hessian for the model  $\mathfrak{T}_i$  is the combination of the single red block for residue  $i$ , the two orange blocks representing the sub-matrices of chi-squared second partial derivatives with respect to the diffusion parameter  $\mathfrak{D}_j$  and the model-free parameter  $\mathfrak{F}_i^k$ , and the single yellow block for that residue. The Hessian for the model-free model  $\mathfrak{F}_i$  is simply the sub-matrix for the residue  $i$  coloured yellow.

## 8.5 The value, gradient, and Hessian dependency chain

The dependency chain which was outlined in the model-free chapter – that the chi-squared function is dependent on the transformed relaxation equations which are dependent on the relaxation equations which themselves are dependent on the spectral density functions – combine with the values, gradients, and Hessians to create a complex web of dependencies. The relationship between all the values, gradients, and Hessians are outlined in Figure 8.3.

## 8.6 The $\chi^2$ value, gradient, and Hessian

### 8.6.1 The $\chi^2$ value

As was presented in Equation (6.1) on page 33 the  $\chi^2$  value is

$$\chi^2(\theta) = \sum_{i=1}^n \frac{(R_i - R_i(\theta))^2}{\sigma_i^2}, \quad (8.15)$$

where the summation index  $i$  ranges over all the relaxation data of all residues used in the analysis.

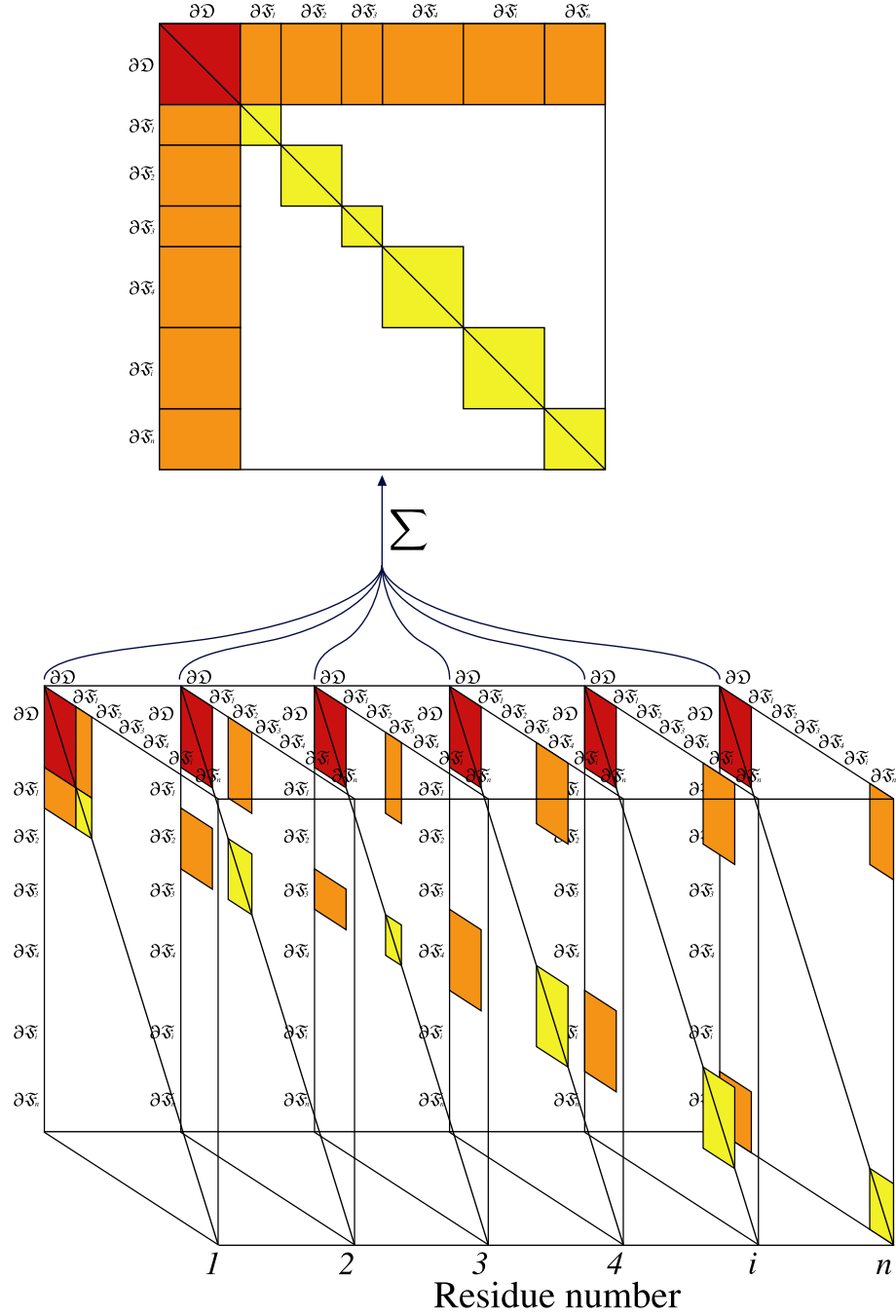


Figure 8.2: The model-free Hessian kite – a demonstration of the construction of the model-free Hessian  $\nabla^2\chi^2$  for the global model  $\mathfrak{S}$ . For each residue  $i$  a different matrix  $\nabla^2\chi_i^2$  is constructed. The first element of the matrix represented by the two symbols  $\partial\mathfrak{D}$  (the red block) is the sub-matrix of chi-squared second partial derivatives with respect to the diffusion tensor parameters  $\mathfrak{D}_j$  and  $\mathfrak{D}_k$ . The orange blocks are the sub-matrices of chi-squared second partial derivatives with respect to the diffusion parameter  $\mathfrak{D}_j$  and the model-free parameter  $\mathfrak{F}_i^k$ . The yellow blocks are the sub-matrices of chi-squared second partial derivatives with respect to the model-free parameters  $\mathfrak{F}_i^j$  and  $\mathfrak{F}_i^k$ . For the residue dependent matrix  $\nabla^2\chi_i^2$  the second partial derivatives with respect to the model-free parameters  $\mathfrak{F}_l^j$  and  $\mathfrak{F}_l^k$  where  $i \neq l$  are zero. In addition, the second partial derivatives with respect to the model-free parameters  $\mathfrak{F}_i^j$  and  $\mathfrak{F}_i^k$  where  $i \neq l$  are also zero. These blocks of sub-matrices are left uncoloured. The complete Hessian of  $\mathfrak{S}$  is the sum of the matrices  $\nabla^2\chi_i^2$ .

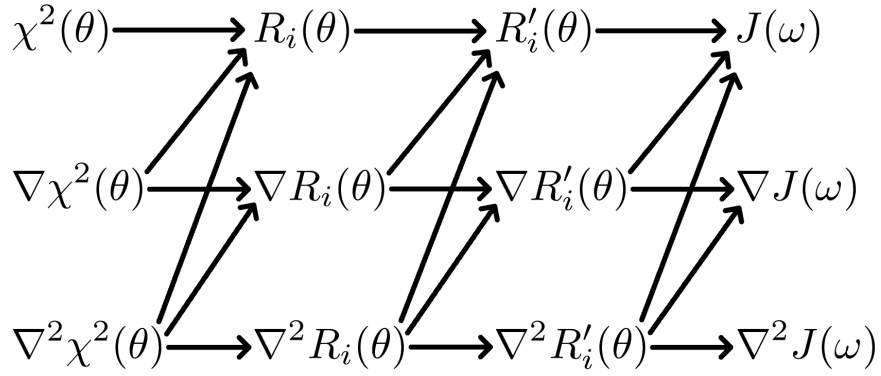


Figure 8.3: Dependencies between the  $\chi^2$ , transformed relaxation, relaxation, and spectral density equations, gradients, and Hessians.

### 8.6.2 The $\chi^2$ gradient

The  $\chi^2$  gradient in vector notation is

$$\nabla \chi^2(\theta) = 2 \sum_{i=1}^n \frac{(R_i - R_i(\theta))^2}{\sigma_i^2} \nabla R_i(\theta). \quad (8.16)$$

### 8.6.3 The $\chi^2$ Hessian

The  $\chi^2$  Hessian in vector notation is

$$\nabla^2 \chi^2(\theta) = 2 \sum_{i=1}^n \frac{1}{\sigma_i^2} (\nabla R_i(\theta) \cdot \nabla R_i(\theta)^T - (R_i - R_i(\theta)) \nabla^2 R_i(\theta)). \quad (8.17)$$

## 8.7 The $R_i(\theta)$ values, gradients, and Hessians

### 8.7.1 The $R_i(\theta)$ values

The  $R_i(\theta)$  values are given by

$$R_1(\theta) = R'_1(\theta), \quad (8.18a)$$

$$R_2(\theta) = R'_2(\theta), \quad (8.18b)$$

$$\text{NOE}(\theta) = 1 + \frac{\gamma_H}{\gamma_X} \frac{\sigma_{\text{NOE}}(\theta)}{R_1(\theta)}. \quad (8.18c)$$

### 8.7.2 The $R_i(\theta)$ gradients

The  $R_i(\theta)$  gradients in vector notation are

$$\nabla R_1(\theta) = \nabla R'_1(\theta), \quad (8.19a)$$

$$\nabla R_2(\theta) = \nabla R'_2(\theta), \quad (8.19b)$$

$$\nabla \text{NOE}(\theta) = \frac{\gamma_H}{\gamma_X} \frac{1}{R_1(\theta)^2} \left( R_1(\theta) \nabla \sigma_{\text{NOE}}(\theta) - \sigma_{\text{NOE}}(\theta) \nabla R_1(\theta) \right). \quad (8.19c)$$

### 8.7.3 The $R_i(\theta)$ Hessians

The  $R_i(\theta)$  Hessians in vector notation are

$$\nabla^2 R_1(\theta) = \nabla^2 R'_1(\theta), \quad (8.20a)$$

$$\nabla^2 R_2(\theta) = \nabla^2 R'_2(\theta), \quad (8.20b)$$

$$\begin{aligned} \nabla^2 \text{NOE}(\theta) = \frac{\gamma_H}{\gamma_X} \frac{1}{R_1(\theta)^3} & \left[ \sigma_{\text{NOE}}(\theta) \left( 2 \nabla R_1(\theta) \cdot \nabla R_1(\theta)^T - R_1(\theta) \nabla^2 R_1(\theta) \right) \right. \\ & \left. - R_1(\theta) \left( \nabla \sigma_{\text{NOE}}(\theta) \cdot \nabla R_1(\theta)^T - R_1(\theta) \nabla^2 \sigma_{\text{NOE}}(\theta) \right) \right]. \end{aligned} \quad (8.20c)$$

## 8.8 $R'_i(\theta)$ values, gradients, and Hessians

The partial and second partial derivatives of the relaxation equations of the set  $R'(\theta)$  are different for each parameter of the vector  $\theta$ . The vector representation of the gradient  $\nabla R'_i(\theta)$  and the matrix representation of the Hessian  $\nabla^2 R'_i(\theta)$  can be reconstructed from the individual elements presented in the next section.

### 8.8.1 Components of the $R'_i(\theta)$ equations

To simplify the calculations of the gradients and Hessians the  $R'_i(\theta)$  equations have been broken down into a number of components. These include the dipolar and CSA constants as well as the dipolar and CSA spectral density terms for each of the three transformed relaxation data types  $\{R_1, R_2, \sigma_{\text{NOE}}\}$ . The segregation of these components simplifies the maths as many partial derivatives of the components are zero.

#### Dipolar constant

The dipolar constant is defined as

$$d = \frac{1}{4} \left( \frac{\mu_0}{4\pi} \right)^2 \frac{(\gamma_H \gamma_X \hbar)^2}{\langle r^6 \rangle}. \quad (8.21)$$

This component of the relaxation equations is independent of the parameter of the spectral density function  $\theta_j$ , the chemical exchange parameter  $\rho_{ex}$ , and the CSA parameter  $\Delta\sigma$ . Therefore the partial and second partial derivatives with respect to these parameters is zero. Only the derivative with respect to the bond length  $r$  is non-zero being

$$d' \equiv \frac{dd}{dr} = -\frac{3}{2} \left( \frac{\mu_0}{4\pi} \right)^2 \frac{(\gamma_H \gamma_X \hbar)^2}{\langle r^7 \rangle}. \quad (8.22)$$

The second derivative with respect to the bond length is

$$d'' \equiv \frac{d^2d}{dr^2} = \frac{21}{2} \left( \frac{\mu_0}{4\pi} \right)^2 \frac{(\gamma_H \gamma_X \hbar)^2}{\langle r^8 \rangle}. \quad (8.23)$$

#### CSA constant

The CSA constant is defined as

$$c = \frac{(\omega_X \cdot \Delta\sigma)^2}{3}. \quad (8.24)$$

The partial derivative of this component with respect to all parameters but the CSA parameter  $\Delta\sigma$  is zero. This derivative is

$$c' \equiv \frac{dc}{d\Delta\sigma} = \frac{2\omega_X^2 \cdot \Delta\sigma}{3}. \quad (8.25)$$

The CSA constant second derivative with respect to  $\Delta\sigma$  is

$$c'' \equiv \frac{d^2c}{d\Delta\sigma^2} = \frac{2\omega_X^2}{3}. \quad (8.26)$$



**$R_{ex}$  constant**

The  $R_{ex}$  constant is defined as

$$R_{ex} = \rho_{ex}(2\pi\omega_H)^2. \quad (8.27)$$

The partial derivative of this component with respect to all parameters but the chemical exchange parameter  $\rho_{ex}$  is zero. This derivative is

$$R'_{ex} \equiv \frac{dR_{ex}}{d\rho_{ex}} = (2\pi\omega_H)^2. \quad (8.28)$$

The  $R_{ex}$  constant second derivative with respect to  $\rho_{ex}$  is

$$R''_{ex} \equiv \frac{d^2 R_{ex}}{d\rho_{ex}^2} = 0. \quad (8.29)$$

**Spectral density terms of the  $R_1$  dipolar component**

For the dipolar component of the  $R_1$  equation (6.3a) on page 34 the spectral density terms are

$$J_d^{R_1} = J(\omega_H - \omega_X) + 3J(\omega_X) + 6J(\omega_H + \omega_X). \quad (8.30)$$

The partial derivative of these terms with respect to the spectral density function parameter  $\theta_j$  is

$$J_d^{R_1'} \equiv \frac{\partial J_d^{R_1}}{\partial \theta_j} = \frac{\partial J(\omega_H - \omega_X)}{\partial \theta_j} + 3 \frac{\partial J(\omega_X)}{\partial \theta_j} + 6 \frac{\partial J(\omega_H + \omega_X)}{\partial \theta_j}. \quad (8.31)$$

The second partial derivative with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  is

$$J_d^{R_1''} \equiv \frac{\partial^2 J_d^{R_1}}{\partial \theta_j \cdot \partial \theta_k} = \frac{\partial^2 J(\omega_H - \omega_X)}{\partial \theta_j \cdot \partial \theta_k} + 3 \frac{\partial^2 J(\omega_X)}{\partial \theta_j \cdot \partial \theta_k} + 6 \frac{\partial^2 J(\omega_H + \omega_X)}{\partial \theta_j \cdot \partial \theta_k}. \quad (8.32)$$

**Spectral density terms of the  $R_1$  CSA component**

For the CSA component of the  $R_1$  equation (6.3a) on page 34 the spectral density terms are

$$J_c^{R_1} = J(\omega_X). \quad (8.33)$$

The partial derivative of these terms with respect to the spectral density function parameter  $\theta_j$  is

$$J_c^{R_1'} \equiv \frac{\partial J_c^{R_1}}{\partial \theta_j} = \frac{\partial J(\omega_X)}{\partial \theta_j}. \quad (8.34)$$

The second partial derivative with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  is

$$J_c^{R_1''} \equiv \frac{\partial^2 J_c^{R_1}}{\partial \theta_j \cdot \partial \theta_k} = \frac{\partial^2 J(\omega_X)}{\partial \theta_j \cdot \partial \theta_k}. \quad (8.35)$$

### Spectral density terms of the $R_2$ dipolar component

For the dipolar component of the  $R_2$  equation (6.3b) on page 34 the spectral density terms are

$$J_d^{R_2} = 4J(0) + J(\omega_H - \omega_X) + 3J(\omega_X) + 6J(\omega_H) + 6J(\omega_H + \omega_X). \quad (8.36)$$

The partial derivative of these terms with respect to the spectral density function parameter  $\theta_j$  is

$$J_d^{R_2'} \equiv \frac{\partial J_d^{R_2}}{\partial \theta_j} = 4 \frac{\partial J(0)}{\partial \theta_j} + \frac{\partial J(\omega_H - \omega_X)}{\partial \theta_j} + 3 \frac{\partial J(\omega_X)}{\partial \theta_j} + 6 \frac{\partial J(\omega_H)}{\partial \theta_j} + 6 \frac{\partial J(\omega_H + \omega_X)}{\partial \theta_j}. \quad (8.37)$$

The second partial derivative with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  is

$$J_d^{R_2''} \equiv \frac{\partial^2 J_d^{R_2}}{\partial \theta_j \cdot \partial \theta_k} = 4 \frac{\partial^2 J(0)}{\partial \theta_j \cdot \partial \theta_k} + \frac{\partial^2 J(\omega_H - \omega_X)}{\partial \theta_j \cdot \partial \theta_k} + 3 \frac{\partial^2 J(\omega_X)}{\partial \theta_j \cdot \partial \theta_k} + 6 \frac{\partial^2 J(\omega_H)}{\partial \theta_j \cdot \partial \theta_k} + 6 \frac{\partial^2 J(\omega_H + \omega_X)}{\partial \theta_j \cdot \partial \theta_k}. \quad (8.38)$$

### Spectral density terms of the $R_2$ CSA component

For the CSA component of the  $R_2$  equation (6.3b) on page 34 the spectral density terms are

$$J_c^{R_2} = 4J(0) + 3J(\omega_X). \quad (8.39)$$

The partial derivative of these terms with respect to the spectral density function parameter  $\theta_j$  is

$$J_c^{R_2'} \equiv \frac{\partial J_c^{R_2}}{\partial \theta_j} = 4 \frac{\partial J(0)}{\partial \theta_j} + 3 \frac{\partial J(\omega_X)}{\partial \theta_j}. \quad (8.40)$$

The second partial derivative with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  is

$$J_c^{R_2''} \equiv \frac{\partial^2 J_c^{R_2}}{\partial \theta_j \cdot \partial \theta_k} = 4 \frac{\partial^2 J(0)}{\partial \theta_j \cdot \partial \theta_k} + 3 \frac{\partial^2 J(\omega_X)}{\partial \theta_j \cdot \partial \theta_k}. \quad (8.41)$$

### Spectral density terms of the $\sigma_{\text{NOE}}$ dipolar component

For the dipolar component of the  $\sigma_{\text{NOE}}$  equation (6.3c) on page 34 the spectral density terms are

$$J_d^{\sigma_{\text{NOE}}} = 6J(\omega_H + \omega_X) - J(\omega_H - \omega_X). \quad (8.42)$$

The partial derivative of these terms with respect to the spectral density function parameter  $\theta_j$  is

$$J_d^{\sigma_{\text{NOE}'}} \equiv \frac{\partial J_d^{\sigma_{\text{NOE}}}}{\partial \theta_j} = 6 \frac{\partial J(\omega_H + \omega_X)}{\partial \theta_j} - \frac{\partial J(\omega_H - \omega_X)}{\partial \theta_j}. \quad (8.43)$$

The second partial derivative with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  is

$$J_d^{\sigma_{\text{NOE}}}'' \equiv \frac{\partial^2 J_d^{\sigma_{\text{NOE}}}}{\partial \theta_j \cdot \partial \theta_k} = 6 \frac{\partial^2 J(\omega_H + \omega_X)}{\partial \theta_j \cdot \partial \theta_k} - \frac{\partial^2 J(\omega_H - \omega_X)}{\partial \theta_j \cdot \partial \theta_k}. \quad (8.44)$$

### 8.8.2 $R'_i(\theta)$ values

Using the components of the relaxation equations defined above the three relaxation equations can be re-expressed as

$$R_1(\theta) = dJ_d^{R_1} + cJ_c^{R_1}, \quad (8.45a)$$

$$R_2(\theta) = \frac{d}{2}J_d^{R_2} + \frac{c}{6}J_c^{R_2}, \quad (8.45b)$$

$$\sigma_{\text{NOE}}(\theta) = dJ_d^{\sigma_{\text{NOE}}}. \quad (8.45c)$$

### 8.8.3 $R'_i(\theta)$ gradients

A different partial derivative exists for the spectral density function parameter  $\theta_j$ , the chemical exchange parameter  $\rho_{ex}$ , CSA parameter  $\Delta\sigma$ , and bond length parameter  $r$ . In model-free analysis the spectral density parameters include both the parameters of the diffusion tensor and the parameters of the various model-free models.

#### $\theta_j$ partial derivative

The partial derivatives of the relaxation equations with respect to the spectral density function parameter  $\theta_j$  are

$$\frac{\partial R_1(\theta)}{\partial \theta_j} = dJ_d^{R_1'} + cJ_c^{R_1'}, \quad (8.46a)$$

$$\frac{\partial R_2(\theta)}{\partial \theta_j} = \frac{d}{2}J_d^{R_2'} + \frac{c}{6}J_c^{R_2'}, \quad (8.46b)$$

$$\frac{\partial \sigma_{\text{NOE}}(\theta)}{\partial \theta_j} = dJ_d^{\sigma_{\text{NOE}}'}. \quad (8.46c)$$

#### $\rho_{ex}$ partial derivative

The partial derivatives of the relaxation equations with respect to the chemical exchange parameter  $\rho_{ex}$  are

$$\frac{\partial R_1(\theta)}{\partial \rho_{ex}} = 0, \quad (8.47a)$$

$$\frac{\partial R_2(\theta)}{\partial \rho_{ex}} = (2\pi\omega_H)^2, \quad (8.47b)$$

$$\frac{\partial \sigma_{\text{NOE}}(\theta)}{\partial \rho_{ex}} = 0. \quad (8.47c)$$

**$\Delta\sigma$  partial derivative**

The partial derivatives of the relaxation equations with respect to the CSA parameter  $\Delta\sigma$  are

$$\frac{\partial R_1(\theta)}{\partial \Delta\sigma} = c' J_c^{R_1}, \quad (8.48a)$$

$$\frac{\partial R_2(\theta)}{\partial \Delta\sigma} = \frac{c'}{6} J_c^{R_2}, \quad (8.48b)$$

$$\frac{\partial \sigma_{\text{NOE}}(\theta)}{\partial \Delta\sigma} = 0. \quad (8.48c)$$

 **$r$  partial derivative**

The partial derivatives of the relaxation equations with respect to the bond length parameter  $r$  are

$$\frac{\partial R_1(\theta)}{\partial r} = d' J_d^{R_1}, \quad (8.49a)$$

$$\frac{\partial R_2(\theta)}{\partial r} = \frac{d'}{2} J_d^{R_2}, \quad (8.49b)$$

$$\frac{\partial \sigma_{\text{NOE}}(\theta)}{\partial r} = d' J_d^{\sigma_{\text{NOE}}}. \quad (8.49c)$$

**8.8.4  $R'_i(\theta)$  Hessians**

Again different second partial derivatives with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$ , the chemical exchange parameter  $\rho_{ex}$ , CSA parameter  $\Delta\sigma$ , and bond length parameter  $r$ . These second partial derivatives are the components of the  $R'_i(\theta)$  Hessian matrices.

 **$\theta_j - \theta_k$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the spectral density function parameters  $\theta_j$  and  $\theta_k$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \theta_j \cdot \partial \theta_k} = d J_d^{R_1''} + c J_c^{R_1''}, \quad (8.50a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \theta_j \cdot \partial \theta_k} = \frac{d}{2} J_d^{R_2''} + \frac{c}{6} J_c^{R_2''}, \quad (8.50b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \theta_j \cdot \partial \theta_k} = d J_d^{\sigma_{\text{NOE}}''}. \quad (8.50c)$$

**$\theta_j - \rho_{ex}$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the spectral density function parameter  $\theta_j$  and the chemical exchange parameter  $\rho_{ex}$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \theta_j \cdot \partial \rho_{ex}} = 0, \quad (8.51a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \theta_j \cdot \partial \rho_{ex}} = 0, \quad (8.51b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \theta_j \cdot \partial \rho_{ex}} = 0. \quad (8.51c)$$

 **$\theta_j - \Delta\sigma$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the spectral density function parameter  $\theta_j$  and the CSA parameter  $\Delta\sigma$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \theta_j \cdot \partial \Delta\sigma} = c' J_c^{\text{R}_1'}, \quad (8.52a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \theta_j \cdot \partial \Delta\sigma} = \frac{c'}{6} J_c^{\text{R}_2'}, \quad (8.52b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \theta_j \cdot \partial \Delta\sigma} = 0. \quad (8.52c)$$

 **$\theta_j - r$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the spectral density function parameter  $\theta_j$  and the bond length parameter  $r$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \theta_j \cdot \partial r} = d' J_d^{\text{R}_1'}, \quad (8.53a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \theta_j \cdot \partial r} = \frac{d'}{2} J_d^{\text{R}_2'}, \quad (8.53b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \theta_j \cdot \partial r} = d' J_d^{\sigma_{\text{NOE}}'}. \quad (8.53c)$$

 **$\rho_{ex} - \rho_{ex}$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the chemical exchange parameter  $\rho_{ex}$  twice are

$$\frac{\partial^2 R_1(\theta)}{\partial \rho_{ex}^2} = 0, \quad (8.54a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \rho_{ex}^2} = 0, \quad (8.54b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \rho_{ex}^2} = 0. \quad (8.54c)$$

**$\rho_{ex} - \Delta\sigma$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the chemical exchange parameter  $\rho_{ex}$  and the CSA parameter  $\Delta\sigma$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \rho_{ex} \cdot \partial \Delta\sigma} = 0, \quad (8.55a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \rho_{ex} \cdot \partial \Delta\sigma} = 0, \quad (8.55b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \rho_{ex} \cdot \partial \Delta\sigma} = 0. \quad (8.55c)$$

 **$\rho_{ex} - r$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the chemical exchange parameter  $\rho_{ex}$  and the bond length parameter  $r$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \rho_{ex} \cdot \partial r} = 0, \quad (8.56a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \rho_{ex} \cdot \partial r} = 0, \quad (8.56b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \rho_{ex} \cdot \partial r} = 0. \quad (8.56c)$$

 **$\Delta\sigma - \Delta\sigma$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the CSA parameter  $\Delta\sigma$  twice are

$$\frac{\partial^2 R_1(\theta)}{\partial \Delta\sigma^2} = c'' J_c^{\text{R}_1}, \quad (8.57a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \Delta\sigma^2} = \frac{c''}{6} J_c^{\text{R}_2}, \quad (8.57b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \Delta\sigma^2} = 0. \quad (8.57c)$$

 **$\Delta\sigma - r$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the CSA parameter  $\Delta\sigma$  and the bond length parameter  $r$  are

$$\frac{\partial^2 R_1(\theta)}{\partial \Delta\sigma \cdot \partial r} = 0, \quad (8.58a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial \Delta\sigma \cdot \partial r} = 0, \quad (8.58b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial \Delta\sigma \cdot \partial r} = 0. \quad (8.58c)$$

**$r - r$  partial derivative**

The second partial derivatives of the relaxation equations with respect to the bond length parameter  $r$  twice are

$$\frac{\partial^2 R_1(\theta)}{\partial r^2} = d'' J_d^{R_1}, \quad (8.59a)$$

$$\frac{\partial^2 R_2(\theta)}{\partial r^2} = \frac{d''}{2} J_d^{R_2}, \quad (8.59b)$$

$$\frac{\partial^2 \sigma_{\text{NOE}}(\theta)}{\partial r^2} = d'' J_d^{\sigma_{\text{NOE}}}. \quad (8.59c)$$

## 8.9 Model-free analysis

### 8.9.1 The model-free equations

In the original model-free analysis of [Lipari and Szabo \(1982a\)](#) the correlation function  $C(\tau)$  of the XH bond vector is approximated by decoupling the internal fluctuations of the bond vector  $C_I(\tau)$  from the correlation function of the overall Brownian rotational diffusion  $C_O(\tau)$  by the equation

$$C(\tau) = C_O(\tau) \cdot C_I(\tau). \quad (8.60)$$

The overall correlation functions of the diffusion of a sphere, spheroid, and ellipsoid are presented respectively in section 8.10.1 on page 95, section 8.11.1 on page 108, and section 8.12.1 on page 112. These three different equations can be combined into one generic correlation function which is independent of the type of diffusion. This generic correlation function is

$$C_O(\tau) = \frac{1}{5} \sum_{i=-k}^k c_i \cdot e^{-\tau/\tau_i}, \quad (8.61)$$

where  $c_i$  are the weights and  $\tau_i$  are correlation times of the exponential terms. In the original model-free analysis of [Lipari and Szabo \(1982a,b\)](#) the internal motions are modelled by the correlation function

$$C_I(\tau) = S^2 + (1 - S^2)e^{-\tau/\tau_e}, \quad (8.62)$$

where  $S^2$  is the generalised Lipari and Szabo order parameter which is related to the amplitude of the motion and  $\tau_e$  is the effective correlation time which is an indicator of the timescale of the motion, albeit being dependent on the value of the order parameter. The order parameter ranges from one for complete rigidity to zero for unrestricted motions. Model-free theory was extended by [Clore et al. \(1990\)](#) to include motions on two timescales by the correlation function

$$C_I(\tau) = S^2 + (1 - S_f^2)e^{-\tau/\tau_f} + (S_f^2 - S^2)e^{-\tau/\tau_s}, \quad (8.63)$$

where the faster of the motions is defined by the order parameter  $S_f^2$  and the correlation time  $\tau_f$ , the slower by the parameters  $S_s^2$  and  $\tau_s$ , and the two order parameter are related by the equation  $S^2 = S_f^2 \cdot S_s^2$ .

The relaxation equations of [Abragam \(1961\)](#) are composed of a sum of power spectral density functions  $J(\omega)$  at five frequencies. The spectral density function is related to the correlation function as the two are a Fourier pair. Applying the Fourier transform to the correlation function composed of the generic diffusion equation and the original model-free correlation function results in the equation

$$J(\omega) = \frac{2}{5} \sum_{i=-k}^k c_i \cdot \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2} \right). \quad (8.64)$$



The Fourier transform using the extended model-free correlation function is

$$J(\omega) = \frac{2}{5} \sum_{i=-k}^k c_i \cdot \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega\tau_f\tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega\tau_s\tau_i)^2} \right). \quad (8.65)$$

### 8.9.2 The original model-free gradient

The model-free gradient of the original spectral density function (8.64) is the vector of partial derivatives of the function with respect to the geometric parameter  $\mathfrak{G}_i$ , the orientational parameter  $\mathfrak{D}_i$ , the order parameter  $S^2$ , and the internal correlation time  $\tau_e$ . The positions in the vector correspond to the model parameters which are being optimised.

#### $\mathfrak{G}_j$ partial derivative

The partial derivative of (8.64) with respect to the geometric parameter  $\mathfrak{G}_j$  is

$$\begin{aligned} \frac{\partial J(\omega)}{\partial \mathfrak{G}_j} = \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( S^2 \frac{1 - (\omega\tau_i)^2}{(1 + (\omega\tau_i)^2)^2} + (1 - S^2) \tau_e^2 \frac{(\tau_e + \tau_i)^2 - (\omega\tau_e\tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2)^2} \right) \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2} \right) \right). \quad (8.66) \end{aligned}$$

#### $\mathfrak{D}_j$ partial derivative

The partial derivative of (8.64) with respect to the orientational parameter  $\mathfrak{D}_j$  is

$$\frac{\partial J(\omega)}{\partial \mathfrak{D}_j} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{S^2}{1 + (\omega\tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2} \right). \quad (8.67)$$

#### $S^2$ partial derivative

The partial derivative of (8.64) with respect to the order parameter  $S^2$  is

$$\frac{\partial J(\omega)}{\partial S^2} = \frac{2}{5} \sum_{i=-k}^k c_i \tau_i \left( \frac{1}{1 + (\omega\tau_i)^2} - \frac{(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2} \right). \quad (8.68)$$

#### $\tau_e$ partial derivative

The partial derivative of (8.64) with respect to the correlation time  $\tau_e$  is

$$\frac{\partial J(\omega)}{\partial \tau_e} = \frac{2}{5} (1 - S^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_e + \tau_i)^2 - (\omega\tau_e\tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega\tau_e\tau_i)^2)^2}. \quad (8.69)$$

### 8.9.3 The original model-free Hessian

The model-free Hessian of the original spectral density function (8.64) is the matrix of second partial derivatives. The matrix coordinates correspond to the model parameters which are being optimised.

#### $\mathfrak{G}_j - \mathfrak{G}_k$ partial derivative

The second partial derivative of (8.64) with respect to the geometric parameters  $\mathfrak{G}_j$  and  $\mathfrak{G}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( -2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \left( S^2 \omega^2 \tau_i \frac{3 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^3} \right. \right. \\ & \left. \left. + (1 - S^2) \tau_e^2 \frac{(\tau_e + \tau_i)^3 + 3\omega^2 \tau_e^3 \tau_i (\tau_e + \tau_i) - (\omega \tau_e)^4 \tau_i^3}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^3} \right) \right. \\ & \left. + \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_k} + \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_j} + c_i \frac{\partial^2 \tau_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \right) \left( S^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \right. \\ & \left. \left. + (1 - S^2) \tau_e^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2} \right) \right. \\ & \left. + \left( \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2} \right) \right) \right). \quad (8.70) \end{aligned}$$

#### $\mathfrak{G}_j - \mathfrak{D}_k$ partial derivative

The second partial derivative of (8.64) with respect to the geometric parameter  $\mathfrak{G}_j$  and the orientational parameter  $\mathfrak{D}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \frac{\partial c_i}{\partial \mathfrak{D}_k} \left( S^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} + (1 - S^2) \tau_e^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2} \right) \right. \\ & \left. + \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2} \right) \right). \quad (8.71) \end{aligned}$$

#### $\mathfrak{G}_j - S^2$ partial derivative

The second partial derivative of (8.64) with respect to the geometric parameter  $\mathfrak{G}_j$  and the order parameter  $S^2$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial S^2} = & \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} - \tau_e^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2} \right) \right. \\ & \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2} \right) \right). \quad (8.72) \end{aligned}$$

**$\mathfrak{G}_j - \tau_e$  partial derivative**

The second partial derivative of (8.64) with respect to the geometric parameter  $\mathfrak{G}_j$  and the correlation time  $\tau_e$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \tau_e} = \frac{2}{5}(1 - S^2) \sum_{i=-k}^k \left( 2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \tau_e \tau_i (\tau_e + \tau_i) \frac{(\tau_e + \tau_i)^2 - 3(\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^3} + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2} \right). \quad (8.73)$$

 **$\mathfrak{D}_j - \mathfrak{D}_k$  partial derivative**

The second partial derivative of (8.64) with respect to the orientational parameters  $\mathfrak{D}_j$  and  $\mathfrak{D}_k$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial^2 c_i}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S^2)(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2} \right). \quad (8.74)$$

 **$\mathfrak{D}_j - S^2$  partial derivative**

The second partial derivative of (8.64) with respect to the orientational parameter  $\mathfrak{D}_j$  and the order parameter  $S^2$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial S^2} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_e + \tau_i)\tau_e}{(\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2} \right). \quad (8.75)$$

 **$\mathfrak{D}_j - \tau_e$  partial derivative**

The second partial derivative of (8.64) with respect to the orientational parameter  $\mathfrak{D}_j$  and the correlation time  $\tau_e$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \tau_e} = \frac{2}{5}(1 - S^2) \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2}. \quad (8.76)$$

 **$S^2 - S^2$  partial derivative**

The second partial derivative of (8.64) with respect to the order parameter  $S^2$  twice is

$$\frac{\partial^2 J(\omega)}{(\partial S^2)^2} = 0. \quad (8.77)$$

**$S^2 - \tau_e$  partial derivative**

The second partial derivative of (8.64) with respect to the order parameter  $S^2$  and correlation time  $\tau_e$  is

$$\frac{\partial^2 J(\omega)}{\partial S^2 \cdot \partial \tau_e} = -\frac{2}{5} \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_e + \tau_i)^2 - (\omega \tau_e \tau_i)^2}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^2}. \quad (8.78)$$

 **$\tau_e - \tau_e$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation time  $\tau_e$  twice is

$$\frac{\partial^2 J(\omega)}{\partial \tau_e^2} = -\frac{4}{5} (1 - S^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_e + \tau_i)^3 + 3\omega^2 \tau_i^3 \tau_e (\tau_e + \tau_i) - (\omega \tau_i)^4 \tau_e^3}{((\tau_e + \tau_i)^2 + (\omega \tau_e \tau_i)^2)^3} \quad (8.79)$$

### 8.9.4 The extended model-free gradient

The model-free gradient of the extended spectral density function (8.65) is the vector of partial derivatives of the function with respect to the geometric parameter  $\mathfrak{G}_i$ , the orientational parameter  $\mathfrak{D}_i$ , the order parameters  $S^2$  and  $S_f^2$ , and the internal correlation times  $\tau_f$  and  $\tau_s$ . The positions in the vector correspond to the model parameters which are being optimised.

#### $\mathfrak{G}_j$ partial derivative

The partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  is

$$\begin{aligned} \frac{\partial J(\omega)}{\partial \mathfrak{G}_j} = & \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( S^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & \left. \left. + (S_f^2 - S^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ & \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \end{aligned} \quad (8.80)$$

#### $\mathfrak{D}_j$ partial derivative

The partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  is

$$\frac{\partial J(\omega)}{\partial \mathfrak{D}_j} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.81)$$

#### $S^2$ partial derivative

The partial derivative of (8.65) with respect to the order parameter  $S^2$  is

$$\frac{\partial J(\omega)}{\partial S^2} = \frac{2}{5} \sum_{i=-k}^k c_i \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.82)$$

#### $S_f^2$ partial derivative

The partial derivative of (8.65) with respect to the order parameter  $S_f^2$  is

$$\frac{\partial J(\omega)}{\partial S_f^2} = -\frac{2}{5} \sum_{i=-k}^k c_i \tau_i \left( \frac{(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} - \frac{(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.83)$$

**$\tau_f$  partial derivative**

The partial derivative of (8.65) with respect to the correlation time  $\tau_f$  is

$$\frac{\partial J(\omega)}{\partial \tau_f} = \frac{2}{5}(1 - S_f^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.84)$$

 **$\tau_s$  partial derivative**

The partial derivative of (8.65) with respect to the correlation time  $\tau_s$  is

$$\frac{\partial J(\omega)}{\partial \tau_s} = \frac{2}{5}(S_f^2 - S^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.85)$$

### 8.9.5 The extended model-free Hessian

The model-free Hessian of the extended spectral density function (8.65) is the matrix of second partial derivatives. The matrix coordinates correspond to the model parameters which are being optimised.

#### $\mathfrak{G}_j - \mathfrak{G}_k$ partial derivative

The second partial derivative of (8.65) with respect to the geometric parameters  $\mathfrak{G}_j$  and  $\mathfrak{G}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( -2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \left( S^2 \omega^2 \tau_i \frac{3 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^3} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^3 + 3\omega^2 \tau_f^3 \tau_i (\tau_f + \tau_i) - (\omega \tau_f)^4 \tau_i^3}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \\ & + (S_f^2 - S^2) \tau_s^2 \frac{(\tau_s + \tau_i)^3 + 3\omega^2 \tau_s^3 \tau_i (\tau_s + \tau_i) - (\omega \tau_s)^4 \tau_i^3}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \Big) \\ & + \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_k} + \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_j} + c_i \frac{\partial^2 \tau_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \right) \left( S^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & + (S_f^2 - S^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \Big) \\ & \left. + \left( \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right) \right). \end{aligned} \quad (8.86)$$

#### $\mathfrak{G}_j - \mathfrak{D}_k$ partial derivative

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the orientational parameter  $\mathfrak{D}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \frac{\partial c_i}{\partial \mathfrak{D}_k} \left( S^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & + (S_f^2 - S^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \Big) \\ & + \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \Big). \end{aligned} \quad (8.87)$$

**$\mathfrak{G}_j - S^2$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the order parameter  $S^2$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial S^2} = \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} - \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \quad (8.88) \end{aligned}$$

 **$\mathfrak{G}_j - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the order parameter  $S_f^2$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial S_f^2} = -\frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} - \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} - \frac{(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \quad (8.89) \end{aligned}$$

 **$\mathfrak{G}_j - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the correlation time  $\tau_f$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \tau_f} = \frac{2}{5} (1 - S_f^2) \sum_{i=-k}^k \left( 2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \tau_f \tau_i (\tau_f + \tau_i) \frac{(\tau_f + \tau_i)^2 - 3(\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \right). \quad (8.90) \end{aligned}$$

 **$\mathfrak{G}_j - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the correlation time  $\tau_s$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \tau_s} = \frac{2}{5} (S_f^2 - S^2) \sum_{i=-k}^k \left( 2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \tau_s \tau_i (\tau_s + \tau_i) \frac{(\tau_s + \tau_i)^2 - 3(\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right). \quad (8.91) \end{aligned}$$



**$\mathfrak{D}_j - \mathfrak{D}_k$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameters  $\mathfrak{D}_j$  and  $\mathfrak{D}_k$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial^2 c_i}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(S_f^2 - S^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.92)$$

 **$\mathfrak{D}_j - S^2$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the order parameter  $S^2$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial S^2} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.93)$$

 **$\mathfrak{D}_j - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the order parameter  $S_f^2$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial S_f^2} = -\frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} - \frac{(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.94)$$

 **$\mathfrak{D}_j - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \tau_f} = \frac{2}{5} (1 - S_f^2) \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.95)$$

 **$\mathfrak{D}_j - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \tau_s} = \frac{2}{5} (S_f^2 - S^2) \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.96)$$

**$S^2 - S^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S^2$  twice is

$$\frac{\partial^2 J(\omega)}{(\partial S^2)^2} = 0. \quad (8.97)$$

 **$S^2 - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameters  $S^2$  and  $S_f^2$  is

$$\frac{\partial^2 J(\omega)}{\partial S^2 \cdot \partial S_f^2} = 0. \quad (8.98)$$

 **$S^2 - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S^2$  and correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial S^2 \cdot \partial \tau_f} = 0. \quad (8.99)$$

 **$S^2 - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S^2$  and correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial S^2 \cdot \partial \tau_s} = -\frac{2}{5} \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.100)$$

 **$S_f^2 - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  twice is

$$\frac{\partial^2 J(\omega)}{(\partial S_f^2)^2} = 0. \quad (8.101)$$

 **$S_f^2 - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  and correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial S_f^2 \cdot \partial \tau_f} = -\frac{2}{5} \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.102)$$

**$S_f^2 - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  and correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial S_f^2 \cdot \partial \tau_s} = \frac{2}{5} \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.103)$$

 **$\tau_f - \tau_f$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation time  $\tau_f$  twice is

$$\frac{\partial^2 J(\omega)}{\partial \tau_f^2} = -\frac{4}{5}(1 - S_f^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^3 + 3\omega^2 \tau_i^3 \tau_f (\tau_f + \tau_i) - (\omega \tau_i)^4 \tau_f^3}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \quad (8.104)$$

 **$\tau_f - \tau_s$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation times  $\tau_f$  and  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial \tau_f \cdot \partial \tau_s} = 0. \quad (8.105)$$

 **$\tau_s - \tau_s$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation time  $\tau_s$  twice is

$$\frac{\partial^2 J(\omega)}{\partial \tau_s^2} = -\frac{4}{5}(S_f^2 - S^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^3 + 3\omega^2 \tau_i^3 \tau_s (\tau_s + \tau_i) - (\omega \tau_i)^4 \tau_s^3}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \quad (8.106)$$

### 8.9.6 The alternative extended model-free gradient

Because of the equation  $S^2 = S_f^2 \cdot S_s^2$  and the form of the extended spectral density function (8.65) a convolution of the model-free space occurs if the model-free parameters  $\{S_f^2, S_s^2, \tau_f, \tau_s\}$  are optimised rather than the parameters  $\{S^2, S_f^2, \tau_f, \tau_s\}$ . This convolution increases the complexity of the gradient. For completeness the first partial derivatives are presented below.

#### $\mathfrak{G}_j$ partial derivative

The partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  is

$$\begin{aligned} \frac{\partial J(\omega)}{\partial \mathfrak{G}_j} = & \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( S_f^2 \cdot S_s^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & \left. \left. + S_f^2 (1 - S_s^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ & \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{S_f^2 \cdot S_s^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{S_f^2 (1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \end{aligned} \quad (8.107)$$

#### $\mathfrak{D}_j$ partial derivative

The partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  is

$$\frac{\partial J(\omega)}{\partial \mathfrak{D}_j} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{S_f^2 \cdot S_s^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{S_f^2 (1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.108)$$

#### $S_f^2$ partial derivative

The partial derivative of (8.65) with respect to the order parameter  $S_f^2$  is

$$\frac{\partial J(\omega)}{\partial S_f^2} = \frac{2}{5} \sum_{i=-k}^k c_i \tau_i \left( \frac{S_s^2}{1 + (\omega \tau_i)^2} - \frac{(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.109)$$

#### $S_s^2$ partial derivative

The partial derivative of (8.65) with respect to the order parameter  $S_s^2$  is

$$\frac{\partial J(\omega)}{\partial S_s^2} = \frac{2}{5} S_f^2 \sum_{i=-k}^k c_i \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.110)$$

**$\tau_f$  partial derivative**

The partial derivative of (8.65) with respect to the correlation time  $\tau_f$  is

$$\frac{\partial J(\omega)}{\partial \tau_f} = \frac{2}{5}(1 - S_f^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.111)$$

 **$\tau_s$  partial derivative**

The partial derivative of (8.65) with respect to the correlation time  $\tau_s$  is

$$\frac{\partial J(\omega)}{\partial \tau_s} = \frac{2}{5} S_f^2 (1 - S_s^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.112)$$

### 8.9.7 The alternative extended model-free Hessian

The model-free Hessian of the extended spectral density function (8.65) is also complicated by the convolution resulting from the use of the parameters  $\{S_f^2, S_s^2, \tau_f, \tau_s\}$ . The second partial derivatives with respect to these parameters are presented below.

#### $\mathfrak{G}_j - \mathfrak{G}_k$ partial derivative

The second partial derivative of (8.65) with respect to the geometric parameters  $\mathfrak{G}_j$  and  $\mathfrak{G}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( -2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \left( S_f^2 \cdot S_s^2 \omega^2 \tau_i \frac{3 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^3} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^3 + 3\omega^2 \tau_f^3 \tau_i (\tau_f + \tau_i) - (\omega \tau_f)^4 \tau_i^3}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \\ & + S_f^2 (1 - S_s^2) \tau_s^2 \frac{(\tau_s + \tau_i)^3 + 3\omega^2 \tau_s^3 \tau_i (\tau_s + \tau_i) - (\omega \tau_s)^4 \tau_i^3}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \Big) \\ & + \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_k} + \frac{\partial \tau_i}{\partial \mathfrak{G}_k} \cdot \frac{\partial c_i}{\partial \mathfrak{G}_j} + c_i \frac{\partial^2 \tau_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \right) \left( S_f^2 \cdot S_s^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & + S_f^2 (1 - S_s^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \Big) \\ & + \left( \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{G}_k} \tau_i \left( \frac{S_f^2 \cdot S_s^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{S_f^2 (1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right) \Big). \end{aligned} \quad (8.113)$$

#### $\mathfrak{G}_j - \mathfrak{D}_k$ partial derivative

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the orientational parameter  $\mathfrak{D}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} = & \frac{2}{5} \sum_{i=-k}^k \left( \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \frac{\partial c_i}{\partial \mathfrak{D}_k} \left( S_f^2 \cdot S_s^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} \right. \right. \\ & + (1 - S_f^2) \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \\ & + S_f^2 (1 - S_s^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \Big) \\ & + \frac{\partial^2 c_i}{\partial \mathfrak{G}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S_f^2 \cdot S_s^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{S_f^2 (1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \Big). \end{aligned} \quad (8.114)$$

**$\mathfrak{G}_j - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the order parameter  $S_f^2$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial S_f^2} = \frac{2}{5} \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( S_s^2 \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} - \tau_f^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \right. \right. \\ \left. \left. + (1 - S_s^2) \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{S_s^2}{1 + (\omega \tau_i)^2} - \frac{(\tau_f + \tau_i) \tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} \right. \right. \\ \left. \left. + \frac{(1 - S_s^2)(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \quad (8.115) \end{aligned}$$

 **$\mathfrak{G}_j - S_s^2$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the order parameter  $S_s^2$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial S_s^2} = \frac{2}{5} S_f^2 \sum_{i=-k}^k \left( c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \left( \frac{1 - (\omega \tau_i)^2}{(1 + (\omega \tau_i)^2)^2} - \tau_s^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right) \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right) \right). \quad (8.116) \end{aligned}$$

 **$\mathfrak{G}_j - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the correlation time  $\tau_f$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \tau_f} = \frac{2}{5} (1 - S_f^2) \sum_{i=-k}^k \left( 2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \tau_f \tau_i (\tau_f + \tau_i) \frac{(\tau_f + \tau_i)^2 - 3(\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2} \right). \quad (8.117) \end{aligned}$$

**$\mathfrak{G}_j - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the geometric parameter  $\mathfrak{G}_j$  and the correlation time  $\tau_s$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{G}_j \cdot \partial \tau_s} = \frac{2}{5} S_f^2 (1 - S_s^2) \sum_{i=-k}^k \left( 2c_i \frac{\partial \tau_i}{\partial \mathfrak{G}_j} \tau_s \tau_i (\tau_s + \tau_i) \frac{(\tau_s + \tau_i)^2 - 3(\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \right. \\ \left. + \frac{\partial c_i}{\partial \mathfrak{G}_j} \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2} \right). \end{aligned} \quad (8.118)$$

 **$\mathfrak{D}_j - \mathfrak{D}_k$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameters  $\mathfrak{D}_j$  and  $\mathfrak{D}_k$  is

$$\begin{aligned} \frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial^2 c_i}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} \tau_i \left( \frac{S_f^2 \cdot S_s^2}{1 + (\omega \tau_i)^2} + \frac{(1 - S_f^2)(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} \right. \\ \left. + \frac{S_f^2(1 - S_s^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \end{aligned} \quad (8.119)$$

 **$\mathfrak{D}_j - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the order parameter  $S_f^2$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial S_f^2} = \frac{2}{5} \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{S_s^2}{1 + (\omega \tau_i)^2} - \frac{(\tau_f + \tau_i)\tau_f}{(\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2} + \frac{(1 - S_s^2)(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.120)$$

 **$\mathfrak{D}_j - S_s^2$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the order parameter  $S_s^2$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial S_s^2} = \frac{2}{5} S_f^2 \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i)\tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.121)$$

 **$\mathfrak{D}_j - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \tau_f} = \frac{2}{5} (1 - S_f^2) \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.122)$$



**$\mathfrak{D}_j - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the orientational parameter  $\mathfrak{D}_j$  and the correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial \mathfrak{D}_j \cdot \partial \tau_s} = \frac{2}{5} S_f^2 (1 - S_s^2) \sum_{i=-k}^k \frac{\partial c_i}{\partial \mathfrak{D}_j} \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.123)$$

 **$S_f^2 - S_f^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  twice is

$$\frac{\partial^2 J(\omega)}{(\partial S_f^2)^2} = 0. \quad (8.124)$$

 **$S_f^2 - S_s^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameters  $S_f^2$  and  $S_s^2$  is

$$\frac{\partial^2 J(\omega)}{\partial S_f^2 \cdot \partial S_s^2} = \frac{2}{5} \sum_{i=-k}^k c_i \tau_i \left( \frac{1}{1 + (\omega \tau_i)^2} - \frac{(\tau_s + \tau_i) \tau_s}{(\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2} \right). \quad (8.125)$$

 **$S_f^2 - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  and correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial S_f^2 \cdot \partial \tau_f} = -\frac{2}{5} \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^2 - (\omega \tau_f \tau_i)^2}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^2}. \quad (8.126)$$

 **$S_f^2 - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_f^2$  and correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial S_f^2 \cdot \partial \tau_s} = \frac{2}{5} (1 - S_s^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.127)$$

 **$S_s^2 - S_s^2$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_s^2$  twice is

$$\frac{\partial^2 J(\omega)}{(\partial S_s^2)^2} = 0. \quad (8.128)$$

**$S_s^2 - \tau_f$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_s^2$  and correlation time  $\tau_f$  is

$$\frac{\partial^2 J(\omega)}{\partial S_s^2 \cdot \partial \tau_f} = 0. \quad (8.129)$$

 **$S_s^2 - \tau_s$  partial derivative**

The second partial derivative of (8.65) with respect to the order parameter  $S_s^2$  and correlation time  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial S_s^2 \cdot \partial \tau_s} = -\frac{2}{5} S_f^2 \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^2 - (\omega \tau_s \tau_i)^2}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^2}. \quad (8.130)$$

 **$\tau_f - \tau_f$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation time  $\tau_f$  twice is

$$\frac{\partial^2 J(\omega)}{\partial \tau_f^2} = -\frac{4}{5} (1 - S_f^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_f + \tau_i)^3 + 3\omega^2 \tau_i^3 \tau_f (\tau_f + \tau_i) - (\omega \tau_i)^4 \tau_f^3}{((\tau_f + \tau_i)^2 + (\omega \tau_f \tau_i)^2)^3} \quad (8.131)$$

 **$\tau_f - \tau_s$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation times  $\tau_f$  and  $\tau_s$  is

$$\frac{\partial^2 J(\omega)}{\partial \tau_f \cdot \partial \tau_s} = 0. \quad (8.132)$$

 **$\tau_s - \tau_s$  partial derivative**

The second partial derivative of (8.64) with respect to the correlation time  $\tau_s$  twice is

$$\frac{\partial^2 J(\omega)}{\partial \tau_s^2} = -\frac{4}{5} S_f^2 (1 - S_s^2) \sum_{i=-k}^k c_i \tau_i^2 \frac{(\tau_s + \tau_i)^3 + 3\omega^2 \tau_i^3 \tau_s (\tau_s + \tau_i) - (\omega \tau_i)^4 \tau_s^3}{((\tau_s + \tau_i)^2 + (\omega \tau_s \tau_i)^2)^3} \quad (8.133)$$

## 8.10 Ellipsoidal diffusion tensor

### 8.10.1 The diffusion equation of the ellipsoid

The correlation function of the Brownian rotational diffusion of an ellipsoid is

$$C_O(\tau) = \frac{1}{5} \sum_{i=-2}^2 c_i e^{-\frac{\tau}{\tau_i}}. \quad (8.134)$$

where  $c_i$  are the weights of the five exponential terms which are dependent on the orientation of the XH bond vector and  $\tau_i$  are the correlation times of the five exponential terms.

### 8.10.2 The weights of the ellipsoid

#### Definitions

The three direction cosines defining the XH bond vector within the diffusion frame are

$$\delta_x = \widehat{XH} \cdot \widehat{\mathfrak{D}}_x, \quad (8.135a)$$

$$\delta_y = \widehat{XH} \cdot \widehat{\mathfrak{D}}_y, \quad (8.135b)$$

$$\delta_z = \widehat{XH} \cdot \widehat{\mathfrak{D}}_z. \quad (8.135c)$$

Let the set of geometric parameters be

$$\mathfrak{G} = \{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r\}, \quad (8.136)$$

and the set of orientational parameters be the Euler angles

$$\mathfrak{D} = \{\alpha, \beta, \gamma\}. \quad (8.137)$$

#### The weights

The five weights  $c_i$  in the correlation function of the Brownian rotational diffusion of an ellipsoid (8.134) are

$$c_{-2} = \frac{1}{4}(d - e), \quad (8.138a)$$

$$c_{-1} = 3\delta_y^2\delta_z^2, \quad (8.138b)$$

$$c_0 = 3\delta_x^2\delta_z^2, \quad (8.138c)$$

$$c_1 = 3\delta_x^2\delta_y^2, \quad (8.138d)$$

$$c_2 = \frac{1}{4}(d + e), \quad (8.138e)$$

where

$$d = 3 (\delta_x^4 + \delta_y^4 + \delta_z^4) - 1, \quad (8.139)$$

$$e = \frac{1}{\Re} \left[ (1 + 3\mathfrak{D}_r) (\delta_x^4 + 2\delta_y^2\delta_z^2) + (1 - 3\mathfrak{D}_r) (\delta_y^4 + 2\delta_x^2\delta_z^2) - 2 (\delta_z^4 + 2\delta_x^2\delta_y^2) \right]. \quad (8.140)$$

The factor  $\Re$  is defined as

$$\Re = \sqrt{1 + 3\mathfrak{D}_r^2}. \quad (8.141)$$

### 8.10.3 The weight gradients of the ellipsoid

#### $\mathfrak{D}_i$ partial derivative

The partial derivatives with respect to the orientational parameter  $\mathfrak{D}_i$  are

$$\frac{\partial c_{-2}}{\partial \mathfrak{D}_i} = 3 \left( \delta_x^3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} + \delta_y^3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_z^3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \right) - \frac{\partial e}{\partial \mathfrak{D}_i}, \quad (8.142a)$$

$$\frac{\partial c_{-1}}{\partial \mathfrak{D}_i} = 6\delta_y\delta_z \left( \delta_y \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \right), \quad (8.142b)$$

$$\frac{\partial c_0}{\partial \mathfrak{D}_i} = 6\delta_x\delta_z \left( \delta_x \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right), \quad (8.142c)$$

$$\frac{\partial c_1}{\partial \mathfrak{D}_i} = 6\delta_x\delta_y \left( \delta_x \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_y \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right), \quad (8.142d)$$

$$\frac{\partial c_2}{\partial \mathfrak{D}_i} = 3 \left( \delta_x^3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} + \delta_y^3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_z^3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \right) + \frac{\partial e}{\partial \mathfrak{D}_i}, \quad (8.142e)$$

where

$$\begin{aligned} \frac{\partial e}{\partial \mathfrak{D}_i} = \frac{1}{\Re} & \left[ (1 + 3\mathfrak{D}_r) \left( \delta_x^3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} + \delta_y\delta_z \left( \delta_y \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \right) \right) \right. \\ & + (1 - 3\mathfrak{D}_r) \left( \delta_y^3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_x\delta_z \left( \delta_x \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right) \right) \\ & \left. - 2 \left( \delta_z^3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_x\delta_y \left( \delta_x \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_y \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right) \right) \right]. \quad (8.143) \end{aligned}$$

**$\tau_m$  partial derivative**

The partial derivatives with respect to the  $\tau_m$  geometric parameter are

$$\frac{\partial c_{-2}}{\partial \tau_m} = 0, \quad (8.144a)$$

$$\frac{\partial c_{-1}}{\partial \tau_m} = 0, \quad (8.144b)$$

$$\frac{\partial c_0}{\partial \tau_m} = 0, \quad (8.144c)$$

$$\frac{\partial c_1}{\partial \tau_m} = 0, \quad (8.144d)$$

$$\frac{\partial c_2}{\partial \tau_m} = 0. \quad (8.144e)$$

 **$\mathfrak{D}_a$  partial derivative**

The partial derivatives with respect to the  $\mathfrak{D}_a$  geometric parameter are

$$\frac{\partial c_{-2}}{\partial \mathfrak{D}_a} = 0, \quad (8.145a)$$

$$\frac{\partial c_{-1}}{\partial \mathfrak{D}_a} = 0, \quad (8.145b)$$

$$\frac{\partial c_0}{\partial \mathfrak{D}_a} = 0, \quad (8.145c)$$

$$\frac{\partial c_1}{\partial \mathfrak{D}_a} = 0, \quad (8.145d)$$

$$\frac{\partial c_2}{\partial \mathfrak{D}_a} = 0. \quad (8.145e)$$

 **$\mathfrak{D}_r$  partial derivative**

The partial derivatives with respect to the  $\mathfrak{D}_r$  geometric parameter are

$$\frac{\partial c_{-2}}{\partial \mathfrak{D}_r} = -\frac{3}{4} \frac{\partial e}{\partial \mathfrak{D}_r}, \quad (8.146a)$$

$$\frac{\partial c_{-1}}{\partial \mathfrak{D}_r} = 0, \quad (8.146b)$$

$$\frac{\partial c_0}{\partial \mathfrak{D}_r} = 0, \quad (8.146c)$$

$$\frac{\partial c_1}{\partial \mathfrak{D}_r} = 0, \quad (8.146d)$$

$$\frac{\partial c_2}{\partial \mathfrak{D}_r} = \frac{3}{4} \frac{\partial e}{\partial \mathfrak{D}_r}, \quad (8.146e)$$

where

$$\frac{\partial e}{\partial \mathfrak{D}_r} = \frac{1}{\mathfrak{R}^3} \left[ (1 - \mathfrak{D}_r) (\delta_x^4 + 2\delta_y^2 \delta_z^2) - (1 + \mathfrak{D}_r) (\delta_y^4 + 2\delta_x^2 \delta_z^2) + 2\mathfrak{D}_r (\delta_z^4 + 2\delta_x^2 \delta_y^2) \right]. \quad (8.147)$$

### 8.10.4 The weight Hessians of the ellipsoid

#### $\mathfrak{D}_i - \mathfrak{D}_j$ partial derivative

The second partial derivatives with respect to the orientational parameters  $\mathfrak{D}_i$  and  $\mathfrak{D}_j$  are

$$\begin{aligned} \frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = & 3 \left( \delta_x^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \right. \\ & + \delta_y^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\ & \left. + \delta_z^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \right) - \frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j}, \end{aligned} \quad (8.148a)$$

$$\begin{aligned} \frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = & 6\delta_y^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \\ & + 12\delta_y \delta_z \left( \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\ & + 6\delta_z^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right), \end{aligned} \quad (8.148b)$$

$$\begin{aligned} \frac{\partial^2 c_0}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = & 6\delta_x^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \\ & + 12\delta_x \delta_z \left( \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \\ & + 6\delta_z^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right), \end{aligned} \quad (8.148c)$$

$$\begin{aligned} \frac{\partial^2 c_1}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = & 6\delta_x^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\ & + 12\delta_x \delta_y \left( \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \\ & + 6\delta_y^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right), \end{aligned} \quad (8.148d)$$

$$\begin{aligned} \frac{\partial^2 c_2}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = & 3 \left( \delta_x^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \right. \\ & + \delta_y^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\ & \left. + \delta_z^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \right) + \frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j}, \end{aligned} \quad (8.148e)$$

where

$$\begin{aligned}
\frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = \frac{1}{\Re} & \left[ (1 + 3\mathfrak{D}_r) \left( \delta_x^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \right. \right. \\
& + \delta_y^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \\
& + \delta_z^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\
& \left. + 2\delta_y \delta_z \left( \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \right) \\
& + (1 - 3\mathfrak{D}_r) \left( \delta_y^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \right. \\
& + \delta_x^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \\
& + \delta_z^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \\
& \left. + 2\delta_x \delta_z \left( \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \right) \\
& - 2 \left( \delta_z^2 \left( \delta_z \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + 3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} \right) \right. \\
& + \delta_x^2 \left( \delta_y \frac{\partial^2 \delta_y}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} \right) \\
& + \delta_y^2 \left( \delta_x \frac{\partial^2 \delta_x}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} + \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \\
& \left. \left. + 2\delta_x \delta_y \left( \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_y}{\partial \mathfrak{D}_j} + \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_x}{\partial \mathfrak{D}_j} \right) \right) \right]. \tag{8.149}
\end{aligned}$$

#### $\mathfrak{D}_i - \tau_m$ partial derivative

The second partial derivatives with respect to the orientational parameter  $\mathfrak{D}_i$  and the geometric parameter  $\tau_m$  are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_i \cdot \partial \tau_m} = 0, \tag{8.150a}$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_i \cdot \partial \tau_m} = 0, \tag{8.150b}$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_i \cdot \partial \tau_m} = 0, \tag{8.150c}$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_i \cdot \partial \tau_m} = 0, \tag{8.150d}$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_i \cdot \partial \tau_m} = 0. \quad (8.150e)$$

### $\mathfrak{D}_i - \mathfrak{D}_a$ partial derivative

The second partial derivatives with respect to the orientational parameter  $\mathfrak{D}_i$  and the geometric parameter  $\mathfrak{D}_a$  are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_a} = 0, \quad (8.151a)$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_a} = 0, \quad (8.151b)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_a} = 0, \quad (8.151c)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_a} = 0, \quad (8.151d)$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_a} = 0. \quad (8.151e)$$

### $\mathfrak{D}_i - \mathfrak{D}_r$ partial derivative

The second partial derivatives with respect to the orientational parameter  $\mathfrak{D}_i$  and the geometric parameter  $\mathfrak{D}_r$  are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = -3 \frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r}, \quad (8.152a)$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = 0, \quad (8.152b)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = 0, \quad (8.152c)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = 0, \quad (8.152d)$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = 3 \frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r}, \quad (8.152e)$$

where

$$\begin{aligned} \frac{\partial^2 e}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_r} = \frac{1}{\mathfrak{R}^3} & \left[ (1 - \mathfrak{D}_r) \left( \delta_x^3 \frac{\partial \delta_x}{\partial \mathfrak{D}_i} + \delta_y \delta_z \left( \delta_y \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_y}{\partial \mathfrak{D}_i} \right) \right) \right. \\ & - (1 + \mathfrak{D}_r) \left( \delta_y^3 \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_x \delta_z \left( \delta_x \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_z \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right) \right) \\ & \left. + 2\mathfrak{D}_r \left( \delta_z^3 \frac{\partial \delta_z}{\partial \mathfrak{D}_i} + \delta_x \delta_y \left( \delta_x \frac{\partial \delta_y}{\partial \mathfrak{D}_i} + \delta_y \frac{\partial \delta_x}{\partial \mathfrak{D}_i} \right) \right) \right]. \end{aligned} \quad (8.153)$$



$\tau_m - \tau_m$  **partial derivative**

The second partial derivatives with respect to the geometric parameter  $\tau_m$  twice are

$$\frac{\partial^2 c_{-2}}{\partial \tau_m^2} = 0, \quad (8.154a)$$

$$\frac{\partial^2 c_{-1}}{\partial \tau_m^2} = 0, \quad (8.154b)$$

$$\frac{\partial^2 c_0}{\partial \tau_m^2} = 0, \quad (8.154c)$$

$$\frac{\partial^2 c_1}{\partial \tau_m^2} = 0, \quad (8.154d)$$

$$\frac{\partial^2 c_2}{\partial \tau_m^2} = 0. \quad (8.154e)$$

 $\tau_m - \mathfrak{D}_a$  **partial derivative**

The second partial derivatives with respect to the geometric parameters  $\tau_m$  and  $\mathfrak{D}_a$  are

$$\frac{\partial^2 c_{-2}}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 0, \quad (8.155a)$$

$$\frac{\partial^2 c_{-1}}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 0, \quad (8.155b)$$

$$\frac{\partial^2 c_0}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 0, \quad (8.155c)$$

$$\frac{\partial^2 c_1}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 0, \quad (8.155d)$$

$$\frac{\partial^2 c_2}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 0. \quad (8.155e)$$

 $\tau_m - \mathfrak{D}_r$  **partial derivative**

The second partial derivatives with respect to the geometric parameters  $\tau_m$  and  $\mathfrak{D}_r$  are

$$\frac{\partial^2 c_{-2}}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0, \quad (8.156a)$$

$$\frac{\partial^2 c_{-1}}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0, \quad (8.156b)$$

$$\frac{\partial^2 c_0}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0, \quad (8.156c)$$

$$\frac{\partial^2 c_1}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0, \quad (8.156d)$$

$$\frac{\partial^2 c_2}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0. \quad (8.156e)$$

**$\mathfrak{D}_a - \mathfrak{D}_a$  partial derivative**

The second partial derivatives with respect to the geometric parameter  $\mathfrak{D}_a$  twice are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_a^2} = 0, \quad (8.157a)$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_a^2} = 0, \quad (8.157b)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_a^2} = 0, \quad (8.157c)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_a^2} = 0, \quad (8.157d)$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_a^2} = 0. \quad (8.157e)$$

 **$\mathfrak{D}_a - \mathfrak{D}_r$  partial derivative**

The second partial derivatives with respect to the geometric parameters  $\mathfrak{D}_a$  and  $\mathfrak{D}_r$  are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0, \quad (8.158a)$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0, \quad (8.158b)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0, \quad (8.158c)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0, \quad (8.158d)$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0. \quad (8.158e)$$

 **$\mathfrak{D}_r - \mathfrak{D}_r$  partial derivative**

The second partial derivatives with respect to the geometric parameter  $\mathfrak{D}_r$  twice are

$$\frac{\partial^2 c_{-2}}{\partial \mathfrak{D}_r^2} = -\frac{3}{4} \frac{\partial^2 e}{\partial \mathfrak{D}_r^2}, \quad (8.159a)$$

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_r^2} = 0, \quad (8.159b)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_r^2} = 0, \quad (8.159c)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_r^2} = 0, \quad (8.159d)$$

$$\frac{\partial^2 c_2}{\partial \mathfrak{D}_r^2} = \frac{3}{4} \frac{\partial^2 e}{\partial \mathfrak{D}_r^2}, \quad (8.159e)$$

where

$$\begin{aligned} \frac{\partial^2 e}{\partial \mathfrak{D}_r^2} = \frac{1}{\mathfrak{R}^5} & \left[ (6\mathfrak{D}_r^2 - 9\mathfrak{D}_r - 1) (\delta_x^4 + 2\delta_y^2 \delta_z^2) \right. \\ & + (6\mathfrak{D}_r^2 + 9\mathfrak{D}_r - 1) (\delta_y^4 + 2\delta_x^2 \delta_z^2) \\ & \left. - 2(6\mathfrak{D}_r^2 - 1) (\delta_z^4 + 2\delta_x^2 \delta_y^2) \right]. \end{aligned} \quad (8.160)$$

### 8.10.5 The correlation times of the ellipsoid

The five correlation times  $\tau_i$  in the correlation function of the Brownian rotational diffusion of an ellipsoid (8.134) on page 95 are

$$\tau_{-2} = (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-1}, \quad (8.161a)$$

$$\tau_{-1} = (6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-1}, \quad (8.161b)$$

$$\tau_0 = (6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-1}, \quad (8.161c)$$

$$\tau_1 = (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-1}, \quad (8.161d)$$

$$\tau_2 = (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-1}, \quad (8.161e)$$

where  $\mathfrak{R}$  is defined in Equation (8.141) on page 96.

### 8.10.6 The correlation time gradients of the ellipsoid

#### $\tau_m$ partial derivative

The partial derivatives with respect to the geometric parameter  $\tau_m$  are

$$\frac{\partial\tau_{-2}}{\partial\tau_m} = \tau_m^{-2}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-2}, \quad (8.162a)$$

$$\frac{\partial\tau_{-1}}{\partial\tau_m} = \tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-2}, \quad (8.162b)$$

$$\frac{\partial\tau_0}{\partial\tau_m} = \tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-2}, \quad (8.162c)$$

$$\frac{\partial\tau_1}{\partial\tau_m} = \tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}, \quad (8.162d)$$

$$\frac{\partial\tau_2}{\partial\tau_m} = \tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-2}. \quad (8.162e)$$

#### $\mathfrak{D}_a$ partial derivative

The partial derivatives with respect to the geometric parameter  $\mathfrak{D}_a$  are

$$\frac{\partial\tau_{-2}}{\partial\mathfrak{D}_a} = 2\mathfrak{R}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-2}, \quad (8.163a)$$

$$\frac{\partial\tau_{-1}}{\partial\mathfrak{D}_a} = (1 + 3\mathfrak{D}_r)(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-2}, \quad (8.163b)$$

$$\frac{\partial\tau_0}{\partial\mathfrak{D}_a} = (1 - 3\mathfrak{D}_r)(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-2}, \quad (8.163c)$$

$$\frac{\partial\tau_1}{\partial\mathfrak{D}_a} = -2(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}, \quad (8.163d)$$

$$\frac{\partial\tau_2}{\partial\mathfrak{D}_a} = -2\mathfrak{R}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-2}. \quad (8.163e)$$

**$\mathfrak{D}_r$  partial derivative**

The partial derivatives with respect to the geometric parameter  $\mathfrak{D}_r$  are

$$\frac{\partial \tau_{-2}}{\partial \mathfrak{D}_r} = 6 \frac{\mathfrak{D}_a \mathfrak{D}_r}{\mathfrak{R}} (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a \mathfrak{R})^{-2}, \quad (8.164a)$$

$$\frac{\partial \tau_{-1}}{\partial \mathfrak{D}_r} = 3\mathfrak{D}_a (6\mathfrak{D}_{iso} - \mathfrak{D}_a (1 + 3\mathfrak{D}_r))^{-2}, \quad (8.164b)$$

$$\frac{\partial \tau_0}{\partial \mathfrak{D}_r} = -3\mathfrak{D}_a (6\mathfrak{D}_{iso} - \mathfrak{D}_a (1 - 3\mathfrak{D}_r))^{-2}, \quad (8.164c)$$

$$\frac{\partial \tau_1}{\partial \mathfrak{D}_r} = 0, \quad (8.164d)$$

$$\frac{\partial \tau_2}{\partial \mathfrak{D}_r} = -6 \frac{\mathfrak{D}_a \mathfrak{D}_r}{\mathfrak{R}} (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a \mathfrak{R})^{-2}. \quad (8.164e)$$

### 8.10.7 The correlation time Hessians of the ellipsoid

#### $\tau_m - \tau_m$ partial derivative

The second partial derivatives with respect to the geometric parameter  $\tau_m$  twice are

$$\frac{\partial^2 \tau_{-2}}{\partial \tau_m^2} = 2\tau_m^{-4}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-3} - 2\tau_m^{-3}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-2}, \quad (8.165a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \tau_m^2} = 2\tau_m^{-4}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3} - 2\tau_m^{-3}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-2}, \quad (8.165b)$$

$$\frac{\partial^2 \tau_0}{\partial \tau_m^2} = 2\tau_m^{-4}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3} - 2\tau_m^{-3}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-2}, \quad (8.165c)$$

$$\frac{\partial^2 \tau_1}{\partial \tau_m^2} = 2\tau_m^{-4}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3} - 2\tau_m^{-3}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}, \quad (8.165d)$$

$$\frac{\partial^2 \tau_2}{\partial \tau_m^2} = 2\tau_m^{-4}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-3} - 2\tau_m^{-3}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-2}. \quad (8.165e)$$

#### $\tau_m - \mathfrak{D}_a$ partial derivative

The second partial derivatives with respect to the geometric parameters  $\tau_m$  and  $\mathfrak{D}_a$  are

$$\frac{\partial^2 \tau_{-2}}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 4\mathfrak{R}\tau_m^{-2}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-3}, \quad (8.166a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 2(1 + 3\mathfrak{D}_r)\tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3}, \quad (8.166b)$$

$$\frac{\partial^2 \tau_0}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 2(1 - 3\mathfrak{D}_r)\tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3}, \quad (8.166c)$$

$$\frac{\partial^2 \tau_1}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = -4\tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3}, \quad (8.166d)$$

$$\frac{\partial^2 \tau_2}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = -4\mathfrak{R}\tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-3}. \quad (8.166e)$$

#### $\tau_m - \mathfrak{D}_r$ partial derivative

The second partial derivatives with respect to the geometric parameters  $\tau_m$  and  $\mathfrak{D}_r$  are

$$\frac{\partial^2 \tau_{-2}}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 12\frac{\mathfrak{D}_a\mathfrak{D}_r}{\mathfrak{R}}\tau_m^{-2}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{R})^{-3}, \quad (8.167a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 6\mathfrak{D}_a\tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3}, \quad (8.167b)$$

$$\frac{\partial^2 \tau_0}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = -6\mathfrak{D}_a\tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3}, \quad (8.167c)$$

$$\frac{\partial^2 \tau_1}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = 0, \quad (8.167d)$$

$$\frac{\partial^2 \tau_2}{\partial \tau_m \cdot \partial \mathfrak{D}_r} = -12\frac{\mathfrak{D}_a\mathfrak{D}_r}{\mathfrak{R}}\tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{R})^{-3}. \quad (8.167e)$$

**$\mathfrak{D}_a - \mathfrak{D}_a$  partial derivative**

The second partial derivatives with respect to the geometric parameter  $\mathfrak{D}_a$  twice are

$$\frac{\partial^2 \tau_{-2}}{\partial \mathfrak{D}_a^2} = 8\mathfrak{K}^2(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-3}, \quad (8.168a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \mathfrak{D}_a^2} = 2(1 + 3\mathfrak{D}_r)^2(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3}, \quad (8.168b)$$

$$\frac{\partial^2 \tau_0}{\partial \mathfrak{D}_a^2} = 2(1 - 3\mathfrak{D}_r)^2(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3}, \quad (8.168c)$$

$$\frac{\partial^2 \tau_1}{\partial \mathfrak{D}_a^2} = 8(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3}, \quad (8.168d)$$

$$\frac{\partial^2 \tau_2}{\partial \mathfrak{D}_a^2} = 8\mathfrak{K}^2(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{K})^{-3}. \quad (8.168e)$$

 **$\mathfrak{D}_a - \mathfrak{D}_r$  partial derivative**

The second partial derivatives with respect to the geometric parameters  $\mathfrak{D}_a$  and  $\mathfrak{D}_r$  are

$$\frac{\partial^2 \tau_{-2}}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 24\mathfrak{D}_a\mathfrak{D}_r(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-3} + 6\frac{\mathfrak{D}_r}{\mathfrak{K}}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-2}, \quad (8.169a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 6\mathfrak{D}_a(1 + 3\mathfrak{D}_r)(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3} + 3(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-2}, \quad (8.169b)$$

$$\frac{\partial^2 \tau_0}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = -6\mathfrak{D}_a(1 - 3\mathfrak{D}_r)(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3} - 3(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-2}, \quad (8.169c)$$

$$\frac{\partial^2 \tau_1}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 0, \quad (8.169d)$$

$$\frac{\partial^2 \tau_2}{\partial \mathfrak{D}_a \cdot \partial \mathfrak{D}_r} = 24\mathfrak{D}_a\mathfrak{D}_r(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{K})^{-3} - 6\frac{\mathfrak{D}_r}{\mathfrak{K}}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{K})^{-2}. \quad (8.169e)$$

 **$\mathfrak{D}_r - \mathfrak{D}_r$  partial derivative**

The second partial derivatives with respect to the geometric parameter  $\mathfrak{D}_r$  twice are

$$\frac{\partial^2 \tau_{-2}}{\partial \mathfrak{D}_r^2} = 72 \left( \frac{\mathfrak{D}_a\mathfrak{D}_r}{\mathfrak{K}} \right)^2 (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-3} + 6\frac{\mathfrak{D}_a}{\mathfrak{K}^3}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-2}, \quad (8.170a)$$

$$\frac{\partial^2 \tau_{-1}}{\partial \mathfrak{D}_r^2} = 18\mathfrak{D}_a^2(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 + 3\mathfrak{D}_r))^{-3}, \quad (8.170b)$$

$$\frac{\partial^2 \tau_0}{\partial \mathfrak{D}_r^2} = 18\mathfrak{D}_a^2(6\mathfrak{D}_{iso} - \mathfrak{D}_a(1 - 3\mathfrak{D}_r))^{-3}, \quad (8.170c)$$

$$\frac{\partial^2 \tau_1}{\partial \mathfrak{D}_r^2} = 0, \quad (8.170d)$$

$$\frac{\partial^2 \tau_2}{\partial \mathfrak{D}_r^2} = 72 \left( \frac{\mathfrak{D}_a\mathfrak{D}_r}{\mathfrak{K}} \right)^2 (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a\mathfrak{K})^{-3} - 6\frac{\mathfrak{D}_a}{\mathfrak{K}^3}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a\mathfrak{K})^{-2}. \quad (8.170e)$$

## 8.11 Spheroidal diffusion tensor

### 8.11.1 The diffusion equation of the spheroid

The correlation function of the Brownian rotational diffusion of a spheroid is

$$C_O(\tau) = \frac{1}{5} \sum_{i=-1}^1 c_i e^{-\frac{\tau}{\tau_i}}. \quad (8.171)$$

where  $c_i$  are the weights of the three exponential terms which are dependent on the orientation of the XH bond vector and  $\tau_i$  are the correlation times of the three exponential terms.

### 8.11.2 The weights of the spheroid

#### Definitions

The direction cosine defining the XH bond vector within the spheroidal diffusion frame is

$$\delta_z = \widehat{XH} \cdot \widehat{\mathfrak{D}}_z. \quad (8.172)$$

Let the set of geometric parameters be

$$\mathfrak{G} = \{\mathfrak{D}_{iso}, \mathfrak{D}_a\}, \quad (8.173)$$

and the set of orientational parameters be the spherical angles

$$\mathfrak{D} = \{\theta, \phi\}. \quad (8.174)$$

#### The weights

The three spheroid weights  $c_i$  in the correlation function of the Brownian rotational diffusion of a spheroid (8.171) are

$$c_{-1} = \frac{1}{4}(3\delta_z^2 - 1)^2, \quad (8.175a)$$

$$c_0 = 3\delta_z^2(1 - \delta_z^2), \quad (8.175b)$$

$$c_1 = \frac{3}{4}(\delta_z^2 - 1)^2. \quad (8.175c)$$



### 8.11.3 The weight gradients of the spheroid

#### $\mathfrak{D}_i$ partial derivative

The partial derivatives with respect to the orientational parameter  $\mathfrak{D}_i$  are

$$\frac{\partial c_{-1}}{\partial \mathfrak{D}_i} = 3\delta_z(3\delta_z^2 - 1)\frac{\partial \delta_z}{\partial \mathfrak{D}_i}, \quad (8.176a)$$

$$\frac{\partial c_0}{\partial \mathfrak{D}_i} = 6\delta_z(1 - 2\delta_z^2)\frac{\partial \delta_z}{\partial \mathfrak{D}_i}, \quad (8.176b)$$

$$\frac{\partial c_1}{\partial \mathfrak{D}_i} = 3\delta_z(\delta_z^2 - 1)\frac{\partial \delta_z}{\partial \mathfrak{D}_i}. \quad (8.176c)$$

### 8.11.4 The weight Hessians of the spheroid

#### $\mathfrak{D}_i - \mathfrak{D}_j$ partial derivative

The second partial derivatives with respect to the orientational parameters  $\mathfrak{D}_i$  and  $\mathfrak{D}_j$  are

$$\frac{\partial^2 c_{-1}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = 3 \left( (9\delta_z^2 - 1) \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \delta_z(3\delta_z^2 - 1) \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} \right), \quad (8.177a)$$

$$\frac{\partial^2 c_0}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = 6 \left( (1 - 6\delta_z^2) \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \delta_z(1 - 2\delta_z^2) \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} \right), \quad (8.177b)$$

$$\frac{\partial^2 c_1}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = 3 \left( (3\delta_z^2 - 1) \frac{\partial \delta_z}{\partial \mathfrak{D}_i} \cdot \frac{\partial \delta_z}{\partial \mathfrak{D}_j} + \delta_z(\delta_z^2 - 1) \frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} \right). \quad (8.177c)$$

### 8.11.5 The correlation times of the spheroid

The three spheroid correlation times  $\tau_i$  in the correlation function of the Brownian rotational diffusion of a spheroid (8.171) are

$$\tau_{-1} = (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-1}, \quad (8.178a)$$

$$\tau_0 = (6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-1}, \quad (8.178b)$$

$$\tau_1 = (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-1}. \quad (8.178c)$$

### 8.11.6 The correlation time gradients of the spheroid

#### $\tau_m$ partial derivative

The partial derivatives with respect to the geometric parameter  $\tau_m$  are

$$\frac{\partial \tau_{-1}}{\partial \tau_m} = \tau_m^{-2} (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-2}, \quad (8.179a)$$

$$\frac{\partial \tau_0}{\partial \tau_m} = \tau_m^{-2} (6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-2}, \quad (8.179b)$$

$$\frac{\partial \tau_1}{\partial \tau_m} = \tau_m^{-2} (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}. \quad (8.179c)$$

#### $\mathfrak{D}_a$ partial derivative

The partial derivatives with respect to the geometric parameter  $\mathfrak{D}_a$  are

$$\frac{\partial \tau_{-1}}{\partial \mathfrak{D}_a} = 2(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-2}, \quad (8.180a)$$

$$\frac{\partial \tau_0}{\partial \mathfrak{D}_a} = (6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-2}, \quad (8.180b)$$

$$\frac{\partial \tau_1}{\partial \mathfrak{D}_a} = -2(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}. \quad (8.180c)$$

### 8.11.7 The correlation time Hessians of the spheroid

#### $\tau_m - \tau_m$ partial derivative

The second partial derivatives with respect to the geometric parameter  $\tau_m$  twice are

$$\frac{\partial^2 \tau_{-1}}{\partial \tau_m^2} = 2\tau_m^{-4} (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-3} - 2\tau_m^{-3} (6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-2}, \quad (8.181a)$$

$$\frac{\partial^2 \tau_0}{\partial \tau_m^2} = 2\tau_m^{-4} (6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-3} - 2\tau_m^{-3} (6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-2}, \quad (8.181b)$$

$$\frac{\partial^2 \tau_1}{\partial \tau_m^2} = 2\tau_m^{-4} (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3} - 2\tau_m^{-3} (6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-2}. \quad (8.181c)$$

**$\tau_m - \mathfrak{D}_a$  partial derivative**

The second partial derivatives with respect to the geometric parameters  $\tau_m$  and  $\mathfrak{D}_a$  are

$$\frac{\partial^2 \tau_{-1}}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 4\tau_m^{-2}(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-3}, \quad (8.182a)$$

$$\frac{\partial^2 \tau_0}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = 2\tau_m^{-2}(6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-3}, \quad (8.182b)$$

$$\frac{\partial^2 \tau_1}{\partial \tau_m \cdot \partial \mathfrak{D}_a} = -4\tau_m^{-2}(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3}. \quad (8.182c)$$

 **$\mathfrak{D}_a - \mathfrak{D}_a$  partial derivative**

The second partial derivatives with respect to the geometric parameter  $\mathfrak{D}_a$  twice are

$$\frac{\partial^2 \tau_{-1}}{\partial \mathfrak{D}_a^2} = 8(6\mathfrak{D}_{iso} - 2\mathfrak{D}_a)^{-3}, \quad (8.183a)$$

$$\frac{\partial^2 \tau_0}{\partial \mathfrak{D}_a^2} = 2(6\mathfrak{D}_{iso} - \mathfrak{D}_a)^{-3}, \quad (8.183b)$$

$$\frac{\partial^2 \tau_1}{\partial \mathfrak{D}_a^2} = 8(6\mathfrak{D}_{iso} + 2\mathfrak{D}_a)^{-3}. \quad (8.183c)$$

## 8.12 Spherical diffusion tensor

### 8.12.1 The diffusion equation of the sphere

The correlation function of the Brownian rotational diffusion of a sphere is

$$C_O(\tau) = \frac{1}{5} e^{-\frac{\tau}{\tau_m}}, \quad (8.184)$$

$$= \frac{1}{5} \sum_{i=0}^0 c_i e^{-\frac{\tau}{\tau_i}}. \quad (8.185)$$

where  $c_i$  is the weight of the single exponential term and  $\tau_i$  is the correlation time of the single exponential term.

### 8.12.2 The weight of the sphere

#### Definitions

The entire diffusion parameter set consists of a single geometric parameter and is

$$\mathfrak{D} = \{\tau_m\}. \quad (8.186)$$

#### Summation terms

The summation indices of the correlation function of the Brownian rotational diffusion of a sphere (8.171) range from  $k = 0$  to  $k = 0$  therefore

$$i \in \{0\}. \quad (8.187)$$

#### The weights

The single weight  $c_i$  in the correlation function of the Brownian rotational diffusion of a sphere (8.171) is

$$c_0 = 1. \quad (8.188)$$

### 8.12.3 The weight gradient of the sphere

#### $\tau_m$ partial derivative

The partial derivative with respect to the geometric parameter  $\tau_m$  is

$$\frac{\partial c_0}{\partial \tau_m} = 0. \quad (8.189)$$

### 8.12.4 The weight Hessian of the sphere

$\tau_m - \tau_m$  **partial derivative**

The second partial derivatives with respect to the geometric parameter  $\tau_m$  twice is

$$\frac{\partial^2 c_0}{\partial \tau_m^2} = 0. \quad (8.190)$$

### 8.12.5 The correlation time of the sphere

The single correlation time  $\tau_i$  of the correlation function of the Brownian rotational diffusion of a sphere (8.171) is

$$\tau_0 = \tau_m. \quad (8.191)$$

### 8.12.6 The correlation time gradient of the sphere

$\tau_m$  **partial derivative**

The partial derivative with respect to the geometric parameter  $\tau_m$  is

$$\frac{\partial \tau_0}{\partial \tau_m} = 1. \quad (8.192)$$

### 8.12.7 The correlation time Hessian of the sphere

$\tau_m - \tau_m$  **partial derivative**

The second partial derivative with respect to the geometric parameter  $\tau_m$  twice is

$$\frac{\partial^2 \tau_0}{\partial \tau_m^2} = 0. \quad (8.193)$$

### 8.13 Ellipsoidal dot product derivatives

#### 8.13.1 The dot product of the ellipsoid

The dot product is defined as

$$\delta_i = \widehat{XH} \cdot \widehat{\mathfrak{D}}_i, \quad (8.194)$$

where  $i$  is one of  $\{x, y, z\}$ ,  $\widehat{XH}$  is a unit vector parallel to the XH bond vector, and  $\widehat{\mathfrak{D}}_i$  is one of the unit vectors defining the diffusion frame. The three diffusion frame unit vectors can be expressed using the Euler angles  $\alpha$ ,  $\beta$ , and  $\gamma$  as

$$\widehat{\mathfrak{D}}_x = \begin{pmatrix} -\sin \alpha \sin \gamma + \cos \alpha \cos \beta \cos \gamma \\ -\sin \alpha \cos \gamma - \cos \alpha \cos \beta \sin \gamma \\ \cos \alpha \sin \beta \end{pmatrix}, \quad (8.195a)$$

$$\widehat{\mathfrak{D}}_y = \begin{pmatrix} \cos \alpha \sin \gamma + \sin \alpha \cos \beta \cos \gamma \\ \cos \alpha \cos \gamma - \sin \alpha \cos \beta \sin \gamma \\ \sin \alpha \sin \beta \end{pmatrix}, \quad (8.195b)$$

$$\widehat{\mathfrak{D}}_z = \begin{pmatrix} -\sin \beta \cos \gamma \\ \sin \beta \sin \gamma \\ \cos \beta \end{pmatrix}. \quad (8.195c)$$

#### 8.13.2 The dot product gradient of the ellipsoid

The partial derivative of the dot product  $\delta_i$  with respect to the orientational parameter  $\mathfrak{D}_j$  is

$$\frac{\partial \delta_i}{\partial \mathfrak{D}_j} = \frac{\partial}{\partial \mathfrak{D}_j} (\widehat{XH} \cdot \widehat{\mathfrak{D}}_i) = \widehat{XH} \frac{\partial \widehat{\mathfrak{D}}_i}{\partial \mathfrak{D}_j} + \frac{\partial \widehat{XH}}{\partial \mathfrak{D}_j} \cdot \widehat{\mathfrak{D}}_i. \quad (8.196)$$

Because  $\widehat{XH}$  is constant and not dependent on the Euler angles its derivative is zero. Therefore

$$\frac{\partial \delta_i}{\partial \mathfrak{D}_j} = \widehat{XH} \frac{\partial \widehat{\mathfrak{D}}_i}{\partial \mathfrak{D}_j}. \quad (8.197)$$

#### The $\widehat{\mathfrak{D}}_x$ gradient

The partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_x$  with respect to the Euler angles are

$$\frac{\partial \widehat{\mathfrak{D}}_x}{\partial \alpha} = \begin{pmatrix} -\cos \alpha \sin \gamma - \sin \alpha \cos \beta \cos \gamma \\ -\cos \alpha \cos \gamma + \sin \alpha \cos \beta \sin \gamma \\ -\sin \alpha \sin \beta \end{pmatrix}, \quad (8.198a)$$

$$\frac{\partial \widehat{\mathfrak{D}}_x}{\partial \beta} = \begin{pmatrix} -\cos \alpha \sin \beta \cos \gamma \\ \cos \alpha \sin \beta \sin \gamma \\ \cos \alpha \cos \beta \end{pmatrix}, \quad (8.198b)$$

$$\frac{\partial \widehat{\mathfrak{D}}_x}{\partial \gamma} = \begin{pmatrix} -\sin \alpha \cos \gamma - \cos \alpha \cos \beta \sin \gamma \\ \sin \alpha \sin \gamma - \cos \alpha \cos \beta \cos \gamma \\ 0 \end{pmatrix}. \quad (8.198c)$$

**The  $\widehat{\mathfrak{D}}_y$  gradient**

The partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_y$  with respect to the Euler angles are

$$\frac{\partial \widehat{\mathfrak{D}}_y}{\partial \alpha} = \begin{pmatrix} -\sin \alpha \sin \gamma + \cos \alpha \cos \beta \cos \gamma \\ -\sin \alpha \cos \gamma - \cos \alpha \cos \beta \sin \gamma \\ \cos \alpha \sin \beta \end{pmatrix}, \quad (8.199a)$$

$$\frac{\partial \widehat{\mathfrak{D}}_y}{\partial \beta} = \begin{pmatrix} -\sin \alpha \sin \beta \cos \gamma \\ \sin \alpha \sin \beta \sin \gamma \\ \sin \alpha \cos \beta \end{pmatrix}, \quad (8.199b)$$

$$\frac{\partial \widehat{\mathfrak{D}}_y}{\partial \gamma} = \begin{pmatrix} \cos \alpha \cos \gamma - \sin \alpha \cos \beta \sin \gamma \\ -\cos \alpha \sin \gamma - \sin \alpha \cos \beta \cos \gamma \\ 0 \end{pmatrix}. \quad (8.199c)$$

**The  $\widehat{\mathfrak{D}}_z$  gradient**

The partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_z$  with respect to the Euler angles are

$$\frac{\partial \widehat{\mathfrak{D}}_z}{\partial \alpha} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \quad (8.200a)$$

$$\frac{\partial \widehat{\mathfrak{D}}_z}{\partial \beta} = \begin{pmatrix} -\cos \beta \cos \gamma \\ \cos \beta \sin \gamma \\ -\sin \beta \end{pmatrix}, \quad (8.200b)$$

$$\frac{\partial \widehat{\mathfrak{D}}_z}{\partial \gamma} = \begin{pmatrix} \sin \beta \sin \gamma \\ \sin \beta \cos \gamma \\ 0 \end{pmatrix}. \quad (8.200c)$$

### 8.13.3 The dot product Hessian of the ellipsoid

The second partial derivative of the dot product  $\delta_i$  with respect to the orientational parameters  $\mathfrak{D}_j$  and  $\mathfrak{D}_k$  is

$$\frac{\partial^2 \delta_i}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} = \frac{\partial^2}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k} \left( \widehat{XH} \cdot \widehat{\mathfrak{D}}_i \right) = \widehat{XH} \frac{\partial^2 \widehat{\mathfrak{D}}_i}{\partial \mathfrak{D}_j \cdot \partial \mathfrak{D}_k}. \quad (8.201)$$

#### The $\widehat{\mathfrak{D}}_x$ Hessian

The second partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_x$  with respect to the Euler angles are

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \alpha^2} = \begin{pmatrix} \sin \alpha \sin \gamma - \cos \alpha \cos \beta \cos \gamma \\ \sin \alpha \cos \gamma + \cos \alpha \cos \beta \sin \gamma \\ -\cos \alpha \sin \beta \end{pmatrix}, \quad (8.202a)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \alpha \cdot \partial \beta} = \begin{pmatrix} \sin \alpha \sin \beta \cos \gamma \\ -\sin \alpha \sin \beta \sin \gamma \\ -\sin \alpha \cos \beta \end{pmatrix}, \quad (8.202b)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \alpha \cdot \partial \gamma} = \begin{pmatrix} -\cos \alpha \cos \gamma + \sin \alpha \cos \beta \sin \gamma \\ \cos \alpha \sin \gamma + \sin \alpha \cos \beta \cos \gamma \\ 0 \end{pmatrix}, \quad (8.202c)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \beta^2} = \begin{pmatrix} -\cos \alpha \cos \beta \cos \gamma \\ \cos \alpha \cos \beta \sin \gamma \\ -\cos \alpha \sin \beta \end{pmatrix}, \quad (8.202d)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \beta \cdot \partial \gamma} = \begin{pmatrix} \cos \alpha \sin \beta \sin \gamma \\ \cos \alpha \sin \beta \cos \gamma \\ 0 \end{pmatrix}, \quad (8.202e)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_x}{\partial \gamma^2} = \begin{pmatrix} \sin \alpha \sin \gamma - \cos \alpha \cos \beta \cos \gamma \\ \sin \alpha \cos \gamma + \cos \alpha \cos \beta \sin \gamma \\ 0 \end{pmatrix}. \quad (8.202f)$$

#### The $\widehat{\mathfrak{D}}_y$ Hessian

The second partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_y$  with respect to the Euler angles are

$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \alpha^2} = \begin{pmatrix} -\cos \alpha \sin \gamma - \sin \alpha \cos \beta \cos \gamma \\ -\cos \alpha \cos \gamma + \sin \alpha \cos \beta \sin \gamma \\ -\sin \alpha \sin \beta \end{pmatrix}, \quad (8.203a)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \alpha \cdot \partial \beta} = \begin{pmatrix} -\cos \alpha \sin \beta \cos \gamma \\ \cos \alpha \sin \beta \sin \gamma \\ \cos \alpha \cos \beta \end{pmatrix}, \quad (8.203b)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \alpha \cdot \partial \gamma} = \begin{pmatrix} -\sin \alpha \cos \gamma - \cos \alpha \cos \beta \sin \gamma \\ \sin \alpha \sin \gamma - \cos \alpha \cos \beta \cos \gamma \\ 0 \end{pmatrix}, \quad (8.203c)$$



$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \beta^2} = \begin{pmatrix} -\sin \alpha \cos \beta \cos \gamma \\ \sin \alpha \cos \beta \sin \gamma \\ -\sin \alpha \sin \beta \end{pmatrix}, \quad (8.203d)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \beta \cdot \partial \gamma} = \begin{pmatrix} \sin \alpha \sin \beta \sin \gamma \\ \sin \alpha \sin \beta \cos \gamma \\ 0 \end{pmatrix}, \quad (8.203e)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_y}{\partial \gamma^2} = \begin{pmatrix} -\cos \alpha \sin \gamma - \sin \alpha \cos \beta \cos \gamma \\ -\cos \alpha \cos \gamma + \sin \alpha \cos \beta \sin \gamma \\ 0 \end{pmatrix}. \quad (8.203f)$$

### The $\widehat{\mathfrak{D}}_z$ Hessian

The second partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_z$  with respect to the Euler angles are

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \alpha^2} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \quad (8.204a)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \alpha \cdot \partial \beta} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \quad (8.204b)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \alpha \cdot \partial \gamma} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}, \quad (8.204c)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \beta^2} = \begin{pmatrix} \sin \beta \cos \gamma \\ -\sin \beta \sin \gamma \\ -\cos \beta \end{pmatrix}, \quad (8.204d)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \beta \cdot \partial \gamma} = \begin{pmatrix} \cos \beta \sin \gamma \\ \cos \beta \cos \gamma \\ 0 \end{pmatrix}, \quad (8.204e)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_z}{\partial \gamma^2} = \begin{pmatrix} \sin \beta \cos \gamma \\ -\sin \beta \sin \gamma \\ 0 \end{pmatrix}. \quad (8.204f)$$

## 8.14 Spheroidal dot product derivatives

### 8.14.1 The dot product of the spheroid

The single dot product of the spheroid is defined as

$$\delta_z = \widehat{XH} \cdot \widehat{\mathfrak{D}}_{\parallel}, \quad (8.205)$$

where  $\widehat{XH}$  is a unit vector parallel to the XH vector.  $\widehat{\mathfrak{D}}_{\parallel}$  is a unit vector parallel to the unique axis of the diffusion tensor and can be expressed using the spherical angles where  $\theta$  is the polar angle and  $\phi$  is the azimuthal angle as

$$\widehat{\mathfrak{D}}_{\parallel} = \begin{pmatrix} \sin \theta \cos \phi \\ \sin \theta \sin \phi \\ \cos \theta \end{pmatrix}. \quad (8.206)$$

### 8.14.2 The dot product gradient of the spheroid

The partial derivative of the dot product with respect to the orientational parameter  $\mathfrak{D}_i$  is

$$\frac{\partial \delta_z}{\partial \mathfrak{D}_i} = \frac{\partial}{\partial \mathfrak{D}_i} (\widehat{XH} \cdot \widehat{\mathfrak{D}}_{\parallel}) = \widehat{XH} \frac{\partial \widehat{\mathfrak{D}}_{\parallel}}{\partial \mathfrak{D}_i} + \frac{\partial \widehat{XH}}{\partial \mathfrak{D}_i} \widehat{\mathfrak{D}}_{\parallel}. \quad (8.207)$$

Because the XH bond vector is constant and not dependent on the spherical angles its derivative is zero. Therefore

$$\frac{\partial \delta_z}{\partial \mathfrak{D}_i} = \widehat{XH} \frac{\partial \widehat{\mathfrak{D}}_{\parallel}}{\partial \mathfrak{D}_i}. \quad (8.208)$$

#### The $\widehat{\mathfrak{D}}_{\parallel}$ gradient

The partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_{\parallel}$  with respect to the spherical angles are

$$\frac{\partial \widehat{\mathfrak{D}}_{\parallel}}{\partial \theta} = \begin{pmatrix} \cos \theta \cos \phi \\ \cos \theta \sin \phi \\ -\sin \theta \end{pmatrix}, \quad (8.209a)$$

$$\frac{\partial \widehat{\mathfrak{D}}_{\parallel}}{\partial \phi} = \begin{pmatrix} -\sin \theta \sin \phi \\ \sin \theta \cos \phi \\ 0 \end{pmatrix}. \quad (8.209b)$$

### 8.14.3 The dot product Hessian of the spheroid

The second partial derivative of the single spheroidal dot product  $\delta_z$  with respect to the orientational parameters  $\mathfrak{D}_i$  and  $\mathfrak{D}_j$  is

$$\frac{\partial^2 \delta_z}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} = \frac{\partial^2}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j} (\widehat{XH} \cdot \widehat{\mathfrak{D}}_{\parallel}) = \widehat{XH} \frac{\partial^2 \widehat{\mathfrak{D}}_{\parallel}}{\partial \mathfrak{D}_i \cdot \partial \mathfrak{D}_j}. \quad (8.210)$$

**The  $\widehat{\mathfrak{D}}_{\parallel}$  Hessian**

The second partial derivatives of the unit vector  $\widehat{\mathfrak{D}}_{\parallel}$  with respect to the spherical angles are

$$\frac{\partial^2 \widehat{\mathfrak{D}}_{\parallel}}{\partial \theta^2} = \begin{pmatrix} -\sin \theta \cos \phi \\ -\sin \theta \sin \phi \\ -\cos \theta \end{pmatrix}, \quad (8.211a)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_{\parallel}}{\partial \theta \cdot \partial \phi} = \begin{pmatrix} -\cos \theta \sin \phi \\ \cos \theta \cos \phi \\ 0 \end{pmatrix}, \quad (8.211b)$$

$$\frac{\partial^2 \widehat{\mathfrak{D}}_{\parallel}}{\partial \phi^2} = \begin{pmatrix} -\sin \theta \cos \phi \\ -\sin \theta \sin \phi \\ 0 \end{pmatrix}. \quad (8.211c)$$



## Chapter 9

# relax development

This chapter is for developers or those who would like to extend the functionality of relax. It is not required for using relax. If you would like to make modifications to the relax source code please subscribe to all the relax mailing lists (see the open source infrastructure chapter for more details). Announcements are sent to “relax-announce at gna.org” whereas “relax-users at gna.org” is the list where discussions about the usage of relax should be posted. “relax-devel at gna.org” is where all discussions about the development of relax including feature requests, program design, or any other discussions relating to relax’s structure or code should be posted. Finally, “relax-commits at gna.org” is where all changes to relax’s code and documentation, as well as changes to the web pages, are automatically sent to. Anyone interested in joining the project should subscribe to all four lists.

### 9.1 Version control using Subversion

The development of relax requires the use of the Subversion (SVN) version control software downloadable from <http://subversion.tigris.org/>. The source code to relax is stored in an SVN repository located at <http://svn.gna.org/svn/relax/>. Every single change which has ever made to the program is recorded within this repository. For more information see the open source infrastructure chapter.

Although the downloadable distribution archives can be modified it is best that the most current and up to date revision (the *head* revision) is modified instead. More information about the basics of version control and how this is implemented in Subversion can be found in the Subversion book located at <http://svnbook.red-bean.com/>.

If you are not currently a relax developer you can check out the head revision, assuming that 1.2 is the current major version number, by typing

```
$ svn co svn://svn.gna.org/svn/relax/1.2 relax
```

Otherwise if you are a developer type

```
$ svn co svn+ssh://xxxxx@svn.gna.org/svn/relax/1.2 relax
```

replacing `xxxxxx` with your Gna! login name. If your version is out of date it can be updated to the latest revision by typing

```
$ svn up
```

Modifications can be made to these sources.

## 9.2 Coding conventions

The following conventions should be followed at all times for any code to be accepted into the relax repository. A Python script which tests if code meets relax's coding conventions can be downloaded from [http://nmr-relax.com/scripts/code\\_validator](http://nmr-relax.com/scripts/code_validator). The main reason for these conventions is for readability. By using a consistent coding style and a high comment ratio, the code becomes much easier to read for non-coders and those new to Python. It significantly decreases the barrier of entry into the relax source code for NMR spectroscopists.

### 9.2.1 Indentation

Indentation should be set to four spaces rather than a tab character. This is the recommendation given in the Python style guide found at <http://www.python.org/doc/essays/styleguide.html>. Emacs should automatically set the tabstop correctly. For vi add the following lines to the `vimrc` file:

```
set tabstop=4
set shiftwidth=4
set expandtab
```

For UNIX systems, including Linux and Mac OS X, the `vimrc` file is `~/.vimrc` whereas in MS Windows the file is `$VIM/_vimrc` which is usually `C:\Program Files\vim\_vimrc`. Certain versions of vim, those within the 6.2 series, contain a bug where the tabstop value cannot be changed using the `vimrc` file (although typing `:set tabstop=4` in vim will fix it). One solution is to edit the file `python.vim` which on GNU/Linux systems is located in the path `/usr/share/vim/ftplugin/`. It contains the two lines

```
" Python always uses a 'tabstop' of 8.
setlocal ts=8
```

If these lines are deleted the bug will be removed. Another way to fix the problem is to install newer versions of the run-time files (which will do the same thing).

### 9.2.2 Doc strings

The following are relax's conventions for docstrings. Many of these are Python conventions.

- Each line of the should be set to no more than 100 characters long (this includes all leading white space). For one line docstrings, the trailing double quotes are ignored.

- The standard Python convention of a one line description separated from a detailed description by an empty line should be adhered to. This line must start with a capital letter and end in a period. This convention is required for certain docstring parsers (see the Python docs).
- All functions should have a docstring describing in detail the function, structure, and organisation of the code.
- A docstring should be followed by an empty line.
- Indentation of the docstring should be the same as that of the first line of code, excluding indented lists, etc.

An example of a single line docstring is:

```
def delete(self):
    """Function for deleting all model-free data."""
```

An example of a multiline docstring is:

```
def aic(chi2, k, n):
    """Akaike's Information Criteria (AIC).

    The formula is::

        AIC = chi2 + 2k

    @param chi2:    The minimised chi-squared value.
    @type chi2:     float
    @param k:       The number of parameters in the model.
    @type k:        int
    @param n:       The dimension of the relaxation data set.
    @type n:        int
    @return:        The AIC value.
    @rtype:         float
    """

    return chi2 + 2.0*k
```

### 9.2.3 Variable, function, and class names

In relax a mixture of both camel case (eg. CamelCase) and lower case with underscores is used. Despite the variability there are fixed rules which should be adhered to. These naming conventions should be observed at all times.

#### Variables and functions

For both variables and functions lower case with underscores between words is always used. This is for readability as the convention is much more fluent than camel case. A few rare

exceptions exist, an example is the Brownian diffusion tensor parameter of anisotropy  $\mathfrak{D}_a$  which is referenced as `cdp.diff_tensor.Da`. As a rule though all new variable or function names should be kept as lower case. An example of this convention for both the variable name and function name is:

```
def assemble_param_vector(self, spin=None, spin_id=None, sim_index=None, model_type=None):
    """Assemble the model-free parameter vector (as numpy array).

    If the spin argument is supplied, then the spin_id argument will be ignored.

    @keyword spin:          The spin data container.
    @type spin:             SpinContainer instance
    @keyword spin_id:       The spin identification string.
    @type spin_id:          str
    @keyword sim_index:     The optional MC simulation index.
    @type sim_index:        int
    @keyword model_type:    The optional parameter set, one of 'all', 'diff', 'mf', or
                            'local_tm'.
    @type model_type:       str or None
    @return:                An array of the parameter values of the model-free model.
    @rtype:                 numpy array
    """

    # Initialise.
    param_vector = []

    # Determine the model type.
    if not model_type:
        model_type = self.determine_param_set_type()

    # Diffusion tensor parameters.
    if model_type == 'diff' or model_type == 'all':
        # Normal parameters.
        if sim_index == None:
            # Spherical diffusion.
            if cdp.diff_tensor.type == 'sphere':
                param_vector.append(cdp.diff_tensor.tm)
```

## Classes

For classes relax uses a mix of camel case (for example all the `RelaxError` objects) and underscores (for example `Model_free`). The first letter in all cases is always capitalised. Generally the camel case is reserved for very low level classes which are involved in the program's infrastructure. Examples include the `RelaxError` code, the threading code, and the `self.relax.data` code. All the data analysis specific code, generic code, interface code, etc. uses underscores between the words with only the first letter capitalised. One exception is the space mapping class `OpenDX`, the reason being that the program is called 'OpenDX'. An example is:

```
class Model_free_main:
    """Class containing functions specific to model-free analysis."""

    def are_mf_params_set(self, spin):
        """Test if the model-free parameter values are set.
```



```

@param spin:    The spin container object.
@type spin:    SpinContainer instance
@return:       The name of the first parameter in the parameter list in which the
               corresponding parameter value is None.  If all parameters are set, then None
               is returned.

@rtype:        str or None
"""

# Deselected residue.
if spin.select == 0:
    return

```

## Long names

If you have a look at a few relax source files, you will notice that the variable, function, and class names can be quite long. For example the model-free function ‘`disassemble_param_vector()`’ and the RelaxError class ‘`RelaxNoSequenceError`’. While this is not normal for coding, it is an important component of relax as it facilitates the reading of the source code by a non-coder or someone not familiar with the codebase. Iteration counters can be single letter variables such as ‘`i`’, ‘`j`’, ‘`k`’, etc., however for all other variables, functions, and classes please attempt to use descriptive names which are instantly identifiable. Please minimise the amount of abbreviations used and only use those which are obvious. For example naming the parameter vector ‘`self.param_vector`’, the relaxation data ‘`relax_data`’, the model selection class ‘`class Model_selection`’, the type of spheroidal diffusion ‘`spheroid_type`’, etc.

### 9.2.4 Whitespace

The following conventions are for general code cleanliness and readability:

- Trailing whitespace should be avoided, although this is not very important.
- All functions should be preceded by two empty lines. The only exception is the first function of the class definition.
- Function arguments should be separated by a comma followed by a single space.
- The assignment operator should be surrounded by spaces, for example ‘`tm=1e-8`’. The exception is function arguments where for example ‘`self.classic_colour(res_num=None,width=0.3)`’.
- The comparison operators should also be surrounded by spaces, e.g. ‘`<`’, ‘`>`’, ‘`==`’, ‘`<=`’, ‘`=>`’, ‘`<>`’, ‘`!=`’, ‘`is`’, and ‘`in`’.

An example which shows most of these conventions is:

```

class Scientific_data(Base_struct_API):
    """The Scientific Python specific data object."""

    # Identification string.

```

```

        self.id = 'scientific'

    def _find_bonded_atom(self, attached_atom, mol_type, res):
        """Find the atom named attached_atom directly bonded to the desired atom.

        @param attached_atom: The name of the attached atom to return.
        @type attached_atom: str
        @param mol_type: The type of the molecule. This can be one of 'protein', 'nucleic acid',
        or 'other'.
        @type mol_type: str
        @param res: The ScientificPython residue object.
        @type res: ScientificPython.residue_instance
        @return: A tuple of information about the bonded atom.
        @rtype: tuple consisting of the atom number (int), atom name (str), element
        name (str), and atomic position (Numeric array of len 3)
        """

        # Init.
        bonded_found = False

        # The attached atom is in the residue.
        if attached_atom in res.atoms:
            # The bonded atom object.
            bonded = res[attached_atom]

```

## 9.2.5 Comments

Comments are a very important component within relax. In the current source code the percentage of comment lines relative to lines of code ranges from 15% to over 30% for different files. The average comment density would be close to 25%. The purpose of having so many comment lines, much more than you would expect from source code, is so that the relax's code is fully self documented. It allows someone who is not familiar with the codebase to read the code and quickly understand what is happening. It simplifies the process of learning and allows NMR spectroscopists who are not coders to dive into the code. If writing code for relax, please attempt to maintain the tradition by aiming towards a 25% comment ratio. The comment should be descriptive of what the code below it is supposed to do. Most importantly the comment explains why that code exists. The script <http://nmr-relax.com/scripts/code.validator> can be used to check the comment density.

## 9.3 Submitting changes to the relax project

### 9.3.1 Submitting changes as a patch

The preferred method for submitting fixes and improvements to the relax source code is by the creation of a patch. If your changes are a fix make sure you have submitted a bug report to the bug tracker located at <https://gna.org/bugs/?group=relax> first. See section 3.3 on page 18 for more details. Two methods can be used to generate the patch – the Unix command `diff` or the Subversion program. The resultant file `patch` of either the `diff` or `svn` command described below can be posted to the “relax-devel at gna.org” mailing list. Please label within your post which version of relax you modified or which

revision the patch is for. Also try to create a commit log message according to the format described in section 9.4.4 on page 128 for one of the relax committers to use as a template for committing the change.

### 9.3.2 Modification of official releases – creating patches with diff

If your modifications have been made to the source code of one of the official relax releases (for example 1.2.2) then the Unix command `diff` can be used to create a patch. A patch file is simply the output of the `diff` command run with the recursive flag and presented in the ‘unified’ format. Therefore two directories need to be compared. If the original sources are located in the directory `relax_orig` and the modified sources in `relax_mod` then the patch can be created by typing

```
$ diff -ur relax_orig relax_mod > patch
```

### 9.3.3 Modification of the latest sources – creating patches with Subversion

If possible changes to the latest sources is preferred. Using the most up to date sources from the relax SVN repository will significantly aid the relax developers to incorporate your changes back into the main development line. To check out the current development line see section 9.1 on page 121 for details. Prior to submitting a patch to the mailing list your sources should be updated to include the most recent changes. To do this type

```
$ svn up
```

and note the revision number to include in your post. The update may cause a conflict if changes added to the repository clash with your modifications. If this occurs see the Subversion book at <http://svnbook.red-bean.com/> for details on how to resolve the conflict or submit a message to the relax-devel list.

Once the sources are up to date your changes can be converted into the patch text file. Using SVN creating a patch is easy. Just type

```
$ svn diff > patch
```

in the base relax directory.

## 9.4 Committers

### 9.4.1 Becoming a committer

Anyone can become a relax developer and obtain commit access to the relax repository. The main criteria for selection by the relax developers is to show good judgement, competence in producing good patches, compliance with the coding and commit log conventions, comportment on the mailing lists, not producing too many bugs, only taking on challenges which can be handled, and the skill in judging your own abilities. You will also need to

have an understanding of the concepts of version control specifically those relating to Subversion. The SVN book at <http://svnbook.red-bean.com/> contains all the version control information you will need. After a number of patches have been submitted and accepted any of the relax developers can propose that you receive commit access. If a number of developers agree while no one says no then commit access will be offered.

One area where coding ability can be demonstrated is within the relax test suite. The addition of tests, especially those where the relax internal data structures of `self.relax.data` are scrutinised, can be a good starting point for learning the structure of relax. This is because the introduction of bugs has no effect on normal program execution. The relax test suite is an ideal proving ground.

If skills in only certain areas of relax development, for example in creation of the documentation, an understanding of C but not python, an understanding of solely the code of the user interface, or an understanding of the code specific to a certain type of data analysis methodology, then partial commit access may be granted. Although you will have the ability to make modifications to any part of the repository please make modifications only those areas for which you have permission.

### 9.4.2 Joining Gna!

The first step in becoming a committer is to create a Gna! account. Go to <https://gna.org/account/register.php> and type in a login name, password, real name, and the email address you would like to use. You will then get an automatic email from Gna! which will contain a link to activate your registration.

### 9.4.3 Joining the relax project

The second step in becoming a committer is to register to become a member of the relax project. Go to the Gna! website (<https://gna.org/>) and login. Click on ‘My Groups’ to go to <https://gna.org/my/groups.php>. In the section ‘Request for inclusion’ type ‘relax’ and hit enter. Select relax and write something in the comments. If you have been approved (see section 9.4.1) you will be added to the project committers list.

### 9.4.4 Format of the commit logs

If you are a relax developer and you have commit access to the repository the following conventions should be followed for all commit messages.

- The length of all lines in the commit log should never exceed 100 characters. This is so that the log message viewed in either emails or by the command prompt command `svn log` is legible.
- The first line of the commit log should be a short description or synopsis of the changes. If the change relates to a bug or a task, include the bug and task number using the notation `type #num` where type is either `bug`, `task` or `support` and `num` is the id number (for example `bug #6503`). This terminology is important because the

Gna! infrastructure knows how to translate this into a link to the issue. Also include a link to the issue.

- The second line should be blank.
- If the commit is a bug fix reported by a non-committer or if the commit originates from a patch posted by a non-committer the next lines should be reserved for crediting. The name of the person and their obfuscated email address (for example `edward_at_nmr-relax_dot_com`) should be included in the message.
- Next should be another blank line.
- If the commit relates to an entry in the bug tracker or to a discussion on the mailing lists then the web address of either the bug report or the mailing list archive message should be cited in the next section (separated from the synopsis or credit section by a blank line). All relevant links should be included to allow easy navigation between the repository, mailing lists, bug tracker, etc. An example is bug #5559 which is located at [https://gna.org/bugs/?func=detailitem&item\\_id=5559](https://gna.org/bugs/?func=detailitem&item_id=5559) and the post to “relax-devel at gna.org” describing the fix to that bug which is located at <https://mail.gna.org/public/relax-devel/2006-03/msg00013.html>.
- A full description with all the details can follow. This description should follow a blank line, can itself be sectioned using blank lines, and finally the log is terminated by one blank line at the end of the message.

An example of a commit message for the closure of a bug is:

Fixing the rest of bug #7241 (<https://gna.org/bugs/?7241>).

Bug #7241 was thought to be fixed in in r2591 and r2593, the commit messages describing the solution being located at <https://mail.gna.org/public/relax-commits/2006-09/msg00064.html> (Message-id: <E1GTgBi-0000R6-4h@subversion.gna.org>) for r2591 and <https://mail.gna.org/public/relax-commits/2006-10/msg00001.html> (Message-id: <E1GTt6C-0005rk-8q@subversion.gna.org>) for r2593.

However this was not the only place that the Scientific Python PDB data structure `peptide_chains` was being accessed. The chains were being accessed in the file `'generic_fns/sequence.py'` when the sequence was being read out of the PDB file. This has now been modified with changes similar to r2591 and r2593.

An example of a commit message for changes relating to a task is:

This change implements half of task #3630 (<https://gna.org/task/?3630>).

The docstring in the generic optimisation function has been modified to clear up the ambiguity caused by supplying the option `'None'` together with Newton optimisation.

One last commit message example is:

Added the API documentation creation (using Epydoc) to the Scons scripts.

The Scons target to create the HTML API documentation is called `'api_manual.html'`. The documentation can be created by typing: `$ scons api_manual.html`

The function `'compile_api_manual_html()'` was added to the `'scons/manuals.py'` file. This function runs the `'epydoc'` command. All the Epydoc options are specified in that function.

### 9.4.5 Discussing major changes

If you are contemplating major changes, either for a bug fix, to add a completely new feature or user function for your own work, to improve the behaviour of part the program, or any other potentially disruptive modifications, please discuss these ideas on the relax-devel mailing list. If the planned changes have the potential to introduce problems the creation of a private branch may be suggested.

## 9.5 Branches

### 9.5.1 Branch creation

If a change is likely to be disruptive or cause breakages in the program, the use of your own temporary branch is recommended. This private branch is a complete copy of one of the main development lines wherein you can make changes without disrupting the other developers. Although called a private branch every change is visible to all other developers and each commit will result in an automatic email to the relax-commits mailing list. Other developers are even able to check out your branch and make modifications to it. Private branches can also be used for testing ideas. If the idea does not work the branch can be deleted from the repository (in reality the branch will always exist between the revision numbers of its creation and deletion and can always be resurrected). For example to create a branch from the main 1.3 development line called `molmol_macros` whereby new Molmol macros are to be written, type

```
$ svn cp svn+ssh://xxxxx@svn.gna.org/svn/relax/1.3 \
svn+ssh://xxxxx@svn.gna.org/svn/relax/branches/molmol_macros
```

replacing `xxxxx` with your login name. You can then check out your private branch by typing

```
$ svn co svn+ssh://xxxxx@svn.gna.org/svn/relax/branches/molmol_macros
```

which will create a directory called `molmol_macros` containing all the relax source files. To have the files placed into a different directory, type the name of that directory at the end of the last command. Modifications can be made to this copy while normal development continues on the main line.

### 9.5.2 Keeping the branch up to date using `svnmerge.py`

As you develop your branch, changes will be occurring simultaneously within the main line. These changes should be merged into your branch on a regular basis to avoid large incompatible changes from forming between the two branches. To simplify this process, the `svnmerge.py` script located at <http://www.orcaware.com/svn/wiki/Svnmerge.py> can be used. It is best to download the trunk version from that page, unless that version is non-functional. Once you have this script, the merging from the main line to your private branch must be initialised by typing, from within the checked out copy of your branch,

```
$ svnmerge.py init
```

This then needs to be committed using the automatically generated log

```
$ svn ci -F svnmerge-commit-message.txt
```

To keep up to date, simply type

```
$ svnmerge.py merge
```

If conflicts have occurred please refer to the Subversion book at <http://svnbook.red-bean.com/> for information on how to resolve the problem. Otherwise, or once fixed, the main line revisions merged into your branch can be committed using the automatically generated log file:

```
$ svn ci -F svnmerge-commit-message.txt
```

### 9.5.3 Merging the branch back into the main line

Once you have completed the modifications desired for your branch, all changes which have occurred in the main line have been merged using `svnmerge.py`, and the changes have been approved for merging back into the main line – then your branch can be merged. First check out a copy of the main line,

```
$ svn co svn+ssh://xxxxx@svn.gna.org/svn/relax/1.3 relax-1.3
```

or update a previously checked out version,

```
$ svn up
```

Then `svnmerge.py` can be utilised again. First initialise the merging process by typing, from within the checked out copy of the main line,

```
$ svnmerge.py init svn+ssh://xxxxx@svn.gna.org/svn/relax/branches/molmol_macros
```

Then commit the change

```
$ svn ci -F svnmerge-commit-message.txt
```

To merge the branch and commit the changes, type

```
$ svnmerge.py merge --bidirectional
```

```
$ svn ci -F svnmerge-commit-message.txt
```

Finally the merge properties need to be removed

```
$ svnmerge.py uninit -S svn+ssh://xxxxx@svn.gna.org/svn/relax/branches/molmol_macros
```

the changes committed

```
$ svn ci -F svnmerge-commit-message.txt
```

and your private branch deleted

```
$ svn rm svn+ssh://xxxxx@svn.gna.org/svn/relax/branches/molmol_macros
```

## 9.6 The SCons build system

The SCons build system was chosen over other build systems including ‘make’ as it is a cross-platform build system which can be used in Unix, GNU/Linux, Mac OS X, and even MS Windows (the correct compilers are nevertheless required). Various components of the program relax can be created using the SCons utility. This includes C module compilation, manual creation, distribution creation, and cleaning up and removing certain files. The file ‘sconstruct’ in the base relax directory, which consists of python code, directs the operation of SCons for the various functions.

### 9.6.1 SCons help

Multiple functions have been built into the ‘sconstruct’ script and the modules of the ‘scons’ directory. Each of these can be selected by specifying different ‘targets’ when running SCons. A description of each target is given by the SCons help system which is accessible by typing ‘scons --help’ in the base relax directory.

### 9.6.2 C module compilation

As described in the installation chapter, typing ‘scons’ in the base directory will create the shared objects or dll files which are imported into Python as modules.

### 9.6.3 Compilation of the user manual (PDF version)

To create the PDF version of the relax user manual type

```
$ scons user_manual.pdf
```

in the base directory. SCons will then run a series of shell commands to create the manual from the L<sup>A</sup>T<sub>E</sub>X sources located in the ‘docs/latex’ directory. This is dependent on the programs ‘latex’, ‘makeindex’, ‘dvips’, and ‘ps2pdf’ being located within the environment’s path.

### 9.6.4 Compilation of the user manual (HTML version)

The HTML version of the relax user manual is made by typing

```
$ scons user_manual.html
```

in the base directory. One command calling the program ‘latex2html’ will be executed which will create HTML pages from the L<sup>A</sup>T<sub>E</sub>X sources.

### 9.6.5 Compilation of the API documentation (HTML version)

The HTML version of the relax API documentation is made by typing



```
$ scons api_manual.html
```

in the base directory. The programs Epydoc and Graphviz are required for creating this documentation. The resultant HTML pages will be located in the director 'docs/api/index.html'.

### 9.6.6 Making distribution archives

Two types of distribution archive can be created from the currently checked out sources – the source and binary distributions. To create the source distribution type

```
$ scons source_dist
```

whereas to create the binary distribution, whereby the C modules are compiled and the resultant shared objects are included in the bziped tar file, type

```
$ scons binary_dist
```

If a binary distribution does not exist for your architecture feel free to create it yourself and contribute the archive to be included on the download pages. To do this you will need to check out the appropriate tagged branch from the relax subversion repository. If the current stable release is called 1.2.3 check out that branch by typing

```
$ svn co svn+ssh://bugman@svn.gna.org/svn/relax/tags/1.2.3 relax
```

replacing 'bugman' with your user name if you are a relax developer, otherwise typing

```
$ svn co svn://svn.gna.org/svn/relax/tags/1.2.3 relax
```

Then build the binary distribution and send a message to the relax development mailing list. If compilation does not work please submit a bug to the bug tracker system at <https://gna.org/bugs/?group=relax> detailing the relax version, operation system, architecture, and any other information you believe will help to solve the problem. More information about donating binary distributions to the relax project is given in the open source infrastructure chapter.

### 9.6.7 Cleaning up

If the command

```
$ scons clean
```

is run in the base directory all Python byte compiled files '\*.pyc', all C object files '\*.o' and '\*.os', all C shared object files '\*.so', and any backup files with the extension '\*.bak' are removed from all sub-directories. In addition any temporary L<sup>A</sup>T<sub>E</sub>X compilation files are removed from the 'docs/latex' directory.

## 9.7 The core design of relax

To enable flexibility the internal structure of relax is modular. By construction the large collection of independent data analysis tools can be used individually and relatively easily

by any new code implementing other forms of relaxation data analysis or even by other programs. The core modular design of the program is shown in Figure 9.1.

### 9.7.1 The divisions of relax's source code

relax's source code can be divided into five major areas: the initialisation code, the user interface (UI) code, the functional code, the number crunching code, and the code storing the program state.

**Initialisation:** The code belonging to this section initialises the program, processes the command-line arguments, and determines what mode the program will be run in including the choice of the UI.

**UI:** The user interface. Currently the prompt and the script are the only user interfaces into relax. There are other program modes which are not part of a user interface. These include the test mode in which the program instantly exits and threading mode which is spawned by a parent process and waits for commands. In the future a graphical user interface (GUI), a web based interface, or any other type of interface may be added.

**Functional code:** This code is the main part of the program. It includes anything which does not fit into the other sections and comprises the generic code, the specific code, and the specific setup code used as an interface between the two.

**Number crunching:** The computationally expensive code belongs in this section.

**Program state:** The state of the program is contained within the data structure `self.relax.data` which is accessible from all parts of the program. It should only be read by the generic, specific, and number crunching code. Only the generic and specific code should change its contents.

### 9.7.2 The major components of relax

Each of the boxes in Figure 9.1 represents a different grouping of code.

**relax:** The top level module. This initialises the entire program, tests the dependencies, places the custom errors into the module `__builtin__`, and prints the program's introduction message.

**Command line arguments:** This code processes the arguments supplied to the program and decides whether to print the help message, initialise the prompt, execute a script, initialise a different UI, run the program in test mode, or run the program as a slave thread.

**Prompt:** The main user interface consisting of a Python prompt. The namespace of the interpreter contains the various user functions which are front ends to the generic code. The user functions are simply Python functions which test the supplied arguments to make sure they are of the correct type (string, integer, list, or any other

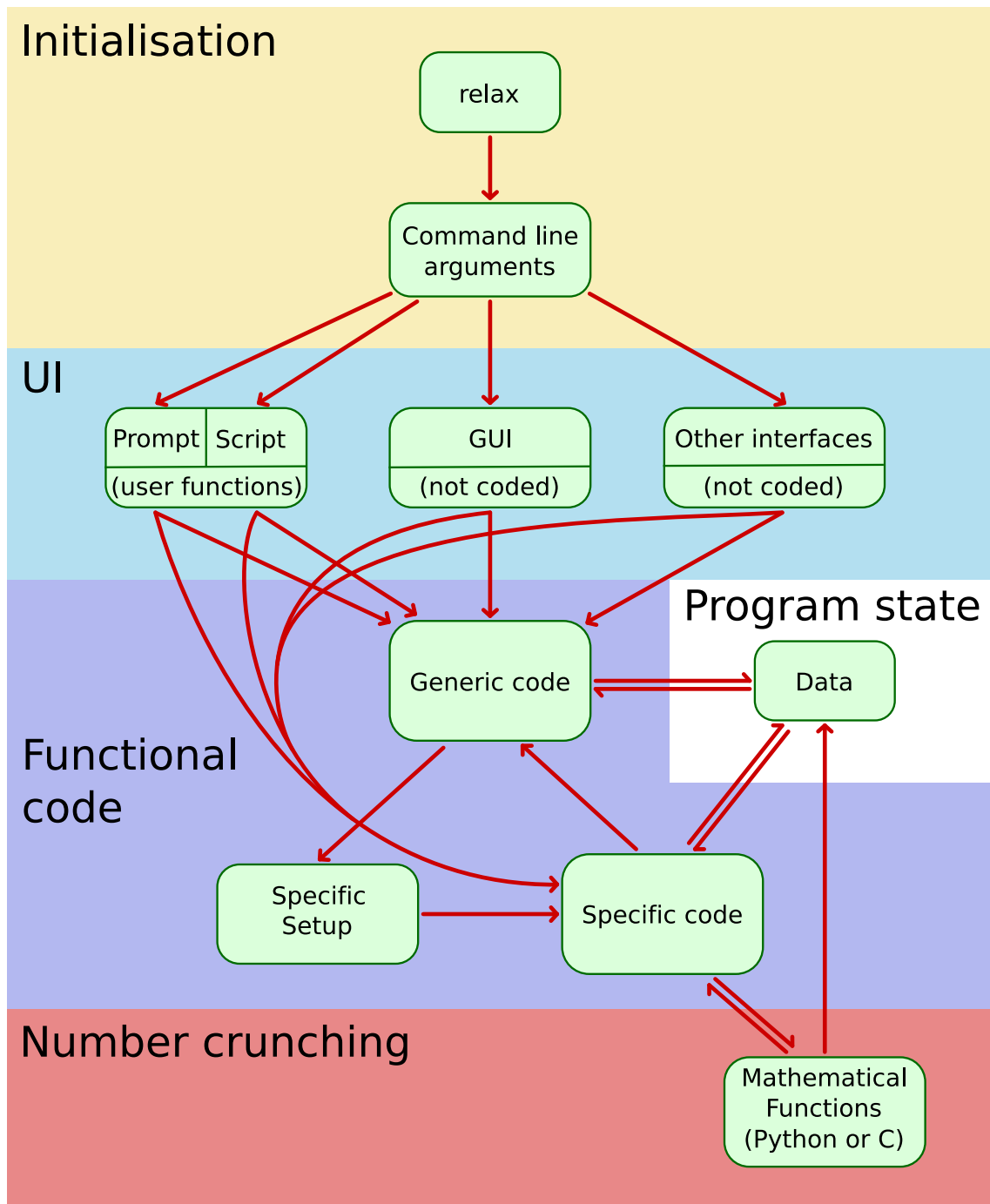


Figure 9.1: The core design of relax.

type) before sending the values to the generic code. The code for the prompt is located in the directory `prompt/`.

**Script:** If a script is supplied on the command line or executed within another user interface it will be run in the same namespace as that of the prompt. Hence the script has access to all the user functions available at the relax prompt. This allows commands which are typed at the prompt to be pasted directly and unmodified into a text file to be run as a script.

**GUI:** The graphical user interface. Although not coded the most mature and least destabilising widget set to use would be QT. The GUI should be relatively easy to tie into relax. The design is such that the GUI can be dropped straight into relax without effecting the normal prompt and script based operation of the program.

**Other interfaces:** Any number of interfaces for example other GUIs, an ncurses interface, a web based interface, or an MPI interface could be added to relax without modification of the current sources.

**Generic code:** This code includes classes and functions which are independent of the UI and not specific to a certain data pipe type, for example not being involved in model-free analysis, relaxation curve-fitting, the NOE calculation, and reduced spectral density mapping. All this code is located in the directory `generic_fns/`.

**Specific setup:** This code implements the internal interface between the generic and specific code. The generic code calls the specific setup asking for a specific function for the given data pipe type. For example by asking for the minimise function when the data pipe type is model-free analysis the function `self.relax.specific.model_free.minimise()` is returned. Although the generic code accesses the specific code solely through this interface the specific code can access the generic code directly. The code is located in the file `specific_fns/specific_setup.py`.

**Specific code:** This is the code which is specific to the data pipe type – model-free analysis, relaxation curve-fitting, reduced spectral density mapping, and the NOE calculation. Each type is located in a separate file in the directory `specific_fns/`.

**Mathematical functions:** This is reserved for CPU intensive code involved in calculations. The code may be written in Python however C code can be used to significantly increase the speed of the calculations. For optimisation the code can include function evaluations, calculation of gradients, and calculation of Hessians. These functions are located in the directory `maths_fns/`.

**Data:** The program state stored in the class `self.relax.data`. This class contains all the program data and is accessed by the generic and specific code. The mathematical functions may also access this data but this is not recommended. The structure is initialised by the file `data.py` and the data is modified solely by the generic and specific code.

## 9.8 The mailing lists

### 9.8.1 Private vs. public messages

If you would like to start a private discussion, please label your email as such. Private messages are however strongly discouraged, only start a private conversation if you really must.

If you receive a reply to a message you have sent, a bug report you have filed, etc. which has not been sent to the mailing list and has not been labelled as private, then the most likely explanation is that ‘reply-to-all’ has not been used and hence the mailing list has not been included on the CC list. If this occurs, please ask the person if the message was meant to be private and refrain from discussing any of the comments within the post. Save these comments until after the person responds by saying that the message was private or re-sends the message to the mailing list. Try to encourage public messages if you think that the post need not be private and if you think that it would be useful for the mailing list archives.

For thread consistency, if you send a message which accidentally misses the mailing list, please do not then forward the previously sent message to the list. For better readability of the mailing list archives, it is best that you create an entirely new message responding to the original post. Just cut and paste your miss-directed message into your new message. That way the thread will be continuous – there will not be any messages missing from the middle of the thread in between the original post and your forwarded message.

To simplify the process of checking if the message was supposed to be private, you could cut and paste the following message (modifying it as you see fit):

The following is the standard pre-composed response to a post not sent to the relax mailing lists and not labelled as private. If you would like to start a private conversation about relax, please label your message as such. If you really must start a private exchange, please respond to this message saying so. If your message was meant to be sent to the relax mailing list, please resend the message hitting ‘reply-to-all’ or making sure that the mailing list is in the CC field. Please do not forward your message, for thread consistency in the mailing list archives sending a new message in response to the original post with the text of the old is best.

## 9.9 The bug, task, and support request trackers

relax’s infrastructure includes three different issue trackers. These are the [bug tracker](#), the [task tracker](#), and the [support request tracker](#).

### 9.9.1 Submitting a bug report

If someone reports a bug to one of the relax mailing lists, ask that person if they would like to create a bug report for that problem, pointing them to the submission web page. This is a good starting point to allow the person to become more involved in the relax project.

If they do not respond or say that they would prefer not to, then you can create bug report for the issue linking to the original message and crediting the person for reporting the issue.

### 9.9.2 Assigning an issue to yourself

If you are a relax committer and see an issue which you would like to solve, please assign that issue to yourself before you start work on it. The assignment will prevent duplicated efforts. If you can see an area where relax needs work, feel free to create a report within task tracker and then assign the task to yourself.

### 9.9.3 Closing an issue

When closing an issue (whether a bug report, a task, or a support request) a number of steps need to be taken. The tracker status should be changed to ‘Done’ and the issue ‘Closed’. In addition, a message should be included which states the repository revision and the relax-commits mailing list archive link (with the message-id) in which the issue was solved. If multiple commits were required, then include all the revisions and as many links as possible (if a task required many commits, the relax-commits links could be skipped). An example is [bug #7402](#) where the closing comment was:

```
This documentation bug was fixed in r2641. The commit message is located at
https://mail.gna.org/public/relax-commits/2006-10/msg00073.html (Message-id:
<E1GYG41-0002kK-Jx@subversion.gna.org>).
```

## 9.10 Links, links, and more links

Creating links throughout the relax infrastructure is important for two major reasons – navigation and search engine indexing. When including a link to a post within the mailing list archives, please include the message-id email header. This enables subscribers to the mailing lists to search for the specific message within their local copy of the email messages.

### 9.10.1 Navigation

To be able to easily navigate between the relax infrastructure components – the bug tracker, the task tracker, the support request tracker, the relax-devel mailing list, the commit logs, and the SVN and CVS repositories – try to include as many links as possible.

For example a bug may first be reported on the relax-users mailing list, then placed within the bug tracker, discussed on relax-devel, a fix committed to the repository, and finally the bug report closed. To be able to follow this chain, links are very important (email message-ids are also important). When the bug is first added to the bug tracker, a link to the relax-users mailing list archive message and the message-id should be included. If you start a discussion on relax-devel, try to include links to the bug tracker entry and the relax-users message. When committing a fix to the repository, include links to the bug

report, to the start of the thread in the mailing list archive, and the original message to relax-users. Then when the bug report is closed, include the revision number of the fix and a link to the relax-commits archive message (and message-id). By having all these links, it is then very easy for someone else to jump between the systems and follow the progression of the bug fix.

If you send a message referring to an old post which was sent the relax mailing lists, an old bug report, or any other archived information, please take the time to find that original information in the archives and include a link to it (including the message-id if relevant). It is much more efficient for a single person to hunt down that message than for the many recipients of your post to search for the message themselves. By including the link, you decrease the overhead of following the mailing list.

### 9.10.2 Search engine indexing

Having a large web of links across relax's infrastructure aids in the search engine indexing of the mailing list archives and the <http://nmr-relax.com> web site. The web of links is useful for catching those Google bots. That way the Google searching of the mailing list archives located on the [communication web page](#) will be more up to date. However to increase the search engine ranking of the web site, links to <http://nmr-relax.com> from external sites is required. This is one reason why relax is a registered [freshmeat](#) project.





## Chapter 10

# Alphabetical listing of user functions

The following is a listing with descriptions of all the user functions available within the relax prompt and scripting environments. These are simply an alphabetical list of the docstrings which can normally be viewed in prompt mode by typing `'help(function)'`.

### 10.1 A warning about the formatting

The following documentation of the user functions has been automatically generated by a script which extracts and formats the docstring associated with each function. There may therefore be instances where the formatting has failed or where there are inconsistencies.

### 10.2 The list of functions

Each user function is presented within it's own subsection with the documentation broken into multiple parts: the synopsis, the default arguments, and the sections from the function's docstring.

#### 10.2.1 The synopsis

The synopsis presents a brief description of the function. It is taken as the first line of the docstring when browsing the help system.

#### 10.2.2 Defaults

This section lists all the arguments taken by the function and their default values. To invoke the function type the function name then in brackets type a comma separated list of arguments.

The first argument printed is always ‘self’ but you can safely ignore it. ‘self’ is part of the object oriented programming within Python and is automatically prefixed to the list of arguments you supply. Therefore you can’t provide ‘self’ as the first argument even if you do try.

### 10.2.3 Docstring sectioning

All other sections are created from the sectioning of the user function docstring.

---

## 10.2.4 align\_tensor.copy()

### Synopsis

Function for copying alignment tensor data.

### Defaults

**align\_tensor.copy**(self, tensor\_from=None, pipe\_from=None, tensor\_to=None, pipe\_to=None)

### Keyword Arguments

**tensor\_from**: The identification string of the alignment tensor to copy the data from.

**pipe\_from**: The name of the data pipe to copy the alignment tensor data from.

**tensor\_to**: The identification string of the alignment tensor to copy the data to.

**pipe\_to**: The name of the data pipe to copy the alignment tensor data to.

### Description

This function will copy the alignment tensor data to a new tensor or a new data pipe. The destination data pipe must not contain any alignment tensor data corresponding to the tensor\_to label. If the pipe\_from or pipe\_to arguments are not supplied, then both will default to the current data pipe. Both the tensor\_from and tensor\_to arguments must be supplied.

### Examples

To copy the alignment tensor data corresponding to 'Pf1' from the data pipe 'old' to the current data pipe, type one of:

```
relax> align_tensor.copy('Pf1', 'old')
```

```
relax> align_tensor.copy(tensor_from='Pf1',
pipe_from='old')
```

To copy the alignment tensor data corresponding to 'Otting' from the current data pipe to the data pipe new, type one of:

```
relax> align_tensor.copy('Otting', pipe_to='new')
```

```
relax> align_tensor.copy(tensor_from='Otting',
pipe_to='new')
```

To copy the alignment tensor data of 'Otting' to that of 'Otting new', type one of:

```
relax> align_tensor.copy('Otting',
tensor_to='Otting new')
```

```
relax> align_tensor.copy(tensor_from='Pf1',
tensor_to='Otting new')
```

---

## 10.2.5 align\_tensor.delete()

### Synopsis

Function for deleting alignment tensor data.

### Defaults

**align\_tensor.delete**(self, tensor=None)

### Keyword Arguments

**tensor**: The alignment tensor identification string.

### Description

This function will delete the specified alignment tensor data from the current data pipe.

---

## 10.2.6 align\_tensor.display()

### Synopsis

Function for displaying the alignment tensor information.

### Defaults

**align\_tensor.display**(self, tensor=None)

### Keyword Arguments

**tensor**: The alignment tensor identification string.

---

## 10.2.7 align\_tensor.fix()

### Synopsis

Fix all alignment tensors so that they do not change during optimisation.

## Defaults

`align_tensor.fix(self, id=None, fixed=True)`

## Keyword Arguments

`id`: The alignment tensor identification string.

`fixed`: The flag specifying if the tensors should be fixed or variable.

## Description

If the ID string is left unset, then all alignment tensors will be fixed.

- 1 – {Szz, Sxx-yy, Sxy, Sxz, Syz} (Pales default format),
- 2 – {Axx, Ayy, Axy, Axz, Ayz} (unitless),
- 3 – {Azz, Axx-yy, Axy, Axz, Ayz} (unitless),
- 4 – {Axx, Ayy, Axy, Axz, Ayz} (units of Hertz),
- 5 – {Azz, Axx-yy, Axy, Axz, Ayz} (units of Hertz),
- 6 – {Pxx, Pyy, Pxy, Pxz, Pyz} (unitless),
- 7 – {Pzz, Pxx-yy, Pxy, Pxz, Pyz} (unitless),

Other formats may be added later. The relationship between the Saupe order matrix  $S$  and the alignment tensor  $A$  is

$$S = 3/2 A.$$

---

## 10.2.8 align\_tensor.init()

### Synopsis

Function for initialising the alignment tensor.

### Defaults

`align_tensor.init(self, tensor=None, params=None, scale=1.0, angle_units='deg', param_types=0, errors=False)`

### Keyword Arguments

`tensor`: The alignment tensor identification string.

`params`: The alignment tensor data.

`scale`: The alignment tensor eigenvalue scaling value.

`angle_units`: The units for the angle parameters.

`param_types`: A flag to select different parameter combinations.

`errors`: A flag which determines if the alignment tensor data or its errors are being input.

### Description

Using this function, the alignment tensor data can be set up. The `params` argument should be a tuple of floating point numbers (a list surrounded by round brackets). These correspond to the parameters of the tensor, which can be specified by the `param_types` argument, where the values correspond to

- 0 – {Sxx, Syy, Sxy, Sxz, Syz} (unitless),

The probability matrix  $P$  is related to the alignment tensor  $A$  by

$$A = P - 1/3 I,$$

where  $I$  is the identity matrix. For the alignment tensor to be supplied in Hertz, the bond vectors must all be of equal length.

### Examples

To set a rhombic tensor to the run 'CaM', type one of:

```
relax> align_tensor.init('super media',
(-8.6322e-05, -5.5786e-04, -3.1732e-05,
2.2927e-05, 2.8599e-04), param_types=1)
```

```
relax> align_tensor.init(tensor='super
media', params=(-8.6322e-05, -5.5786e-04,
-3.1732e-05, 2.2927e-05, 2.8599e-04),
param_types=1)
```

---

## 10.2.9 align\_tensor.matrix\_angles()

### Synopsis

Function for calculating the 5D angles between all alignment tensors.

### Defaults

`align_tensor.matrix_angles(self, basis_set=0, tensors=None)`

## Keyword Arguments

**basis\_set:** The basis set to operate with.

**tensors:** A list of the tensors to apply the calculation to. If None, all tensors are used.

## Description

This function will calculate the angles between all loaded alignment tensors for the current data pipe. The matrices are first converted to a 5D vector form and then the angles are calculated. The angles are dependent on the basis set. If the **basis\_set** argument is set to the default of 0, the vectors {Sxx, Syy, Sxy, Sxz, Syz} are used. If the **basis\_set** argument is set to 1, the vectors {Szz, Sxxy, Sxy, Sxz, Syz} are used instead.

---

### 10.2.10 align\_tensor.reduction()

#### Synopsis

Specify that one tensor is a reduction of another.

#### Defaults

**align\_tensor.reduction**(self, full\_tensor=None, red\_tensor=None)

#### Keyword Arguments

**full\_tensor:** The full alignment tensor.

**red\_tensor:** The reduce alignment tensor.

#### Description

Prior to optimisation of the N-state model and Frame Order theories using alignment tensors, which tensor is a reduction of which other tensor must be specified through this user function.

#### Examples

To state that the alignment tensor loaded as 'chi3 C-dom' is a reduction of 'chi3 N-dom', type:

```
relax> align_tensor.reduction(full_tensor='chi3 N-dom', red_tensor='chi3 C-dom')
```

---

### 10.2.11 align\_tensor.set\_domain()

#### Synopsis

Set the domain label for the alignment tensor.

#### Defaults

**align\_tensor.set\_domain**(self, tensor=None, domain=None)

#### Keyword Arguments

**tensor:** The alignment tensor to assign the domain label to.

**domain:** The domain label.

#### Description

Prior to optimisation of the N-state model or Frame Order theories, the domain to which each alignment tensor belongs must be specified.

#### Examples

To link the alignment tensor loaded as 'chi3 C-dom' to the C-terminal domain 'C', type:

```
relax> align_tensor.set_domain(tensor='chi3 C-dom', domain='C')
```

---

### 10.2.12 align\_tensor.svd()

#### Synopsis

Function for calculating the singular values for all tensors and the condition number.

#### Defaults

**align\_tensor.svd**(self, basis\_set=0, tensors=None)

#### Keyword Arguments

**basis\_set:** The basis set to operate with.

**tensors:** A list of the tensors to apply the calculation to. If None, all tensors are used.

## Description

This function will, using SVD, calculate the singular values of all tensors loaded for the current data pipe. If the `basis_set` argument is set to the default of 0, the matrix on which SVD will be performed is composed of the unitary basis set {Sxx, Syy, Sxy, Sxz, Syz} layed out as:

|  |      |      |      |      |      |  |
|--|------|------|------|------|------|--|
|  | Sxx1 | Syy1 | Sxy1 | Sxz1 | Syz1 |  |
|  | Sxx2 | Syy2 | Sxy2 | Sxz2 | Syz2 |  |
|  | Sxx3 | Syy3 | Sxy3 | Sxz3 | Syz3 |  |
|  | .    | .    | .    | .    | .    |  |
|  | .    | .    | .    | .    | .    |  |
|  | .    | .    | .    | .    | .    |  |
|  | SxxN | SyyN | SxyN | SxzN | SyzN |  |

If `basis_set` is set to 1, the geometric basis set consisting of the stretching and skewing parameters Szz and Sxxyy respectively {Szz, Sxxyy, Sxy, Sxz, Syz} will be used instead. The matrix is:

|  |      |        |      |      |      |  |
|--|------|--------|------|------|------|--|
|  | Szz1 | Sxxyy1 | Sxy1 | Sxz1 | Syz1 |  |
|  | Szz2 | Sxxyy2 | Sxy2 | Sxz2 | Syz2 |  |
|  | Szz3 | Sxxyy3 | Sxy3 | Sxz3 | Syz3 |  |
|  | .    | .      | .    | .    | .    |  |
|  | .    | .      | .    | .    | .    |  |
|  | .    | .      | .    | .    | .    |  |
|  | SzzN | SxxyyN | SxyN | SxzN | SyzN |  |

The relationships between the geometric and unitary basis sets are:

$$\begin{aligned} Szz &= - Sxx - Syy, \\ Sxxyy &= Sxx - Syy, \end{aligned}$$

The SVD values and condition number are dependent upon the basis set chosen.

---

### 10.2.13 angle\_diff\_frame()

#### Synopsis

Calculate the angles defining the XH bond vector within the diffusion frame.

#### Defaults

`angle_diff_frame(self)`

#### Description

If the diffusion tensor is isotropic, then nothing will be done.

If the diffusion tensor is axially symmetric, then the angle  $\alpha$  will be calculated for each XH bond vector.

If the diffusion tensor is asymmetric, then the three angles will be calculated.

---

### 10.2.14 bmr.b.citation()

#### Synopsis

Specify a citation to be added the BMRB data file.

#### Defaults

`bmr.b.citation(self, cite_id=None, authors=None, doi=None, pubmed_id=None, full_citation=None, title=None, status='published', type='journal', journal_abbrev=None, journal_full=None, volume=None, issue=None, page_first=None, page_last=None, year=None)`

#### Keyword Arguments

`cite_id`: The citation ID string.

`authors`: The list of authors. Each author element is a list of four elements (the first name, last name, first initial, and middle initials).

`doi`: The DOI number, e.g. "10.1000/182".

`pubmed_id`: The identification code assigned to the publication by PubMed.

`full_citation`: The full citation as given in a reference list.

`title`: The title of the publication.

`status`: The publication status.

`journal_abbrev`: The standard journal abbreviation.

`journal_full`: The full journal name.

`volume`: The volume number.

`issue`: The issue number.

`page_first`: The first page number.

`page_last`: The last page number.

`year`: The publication year.

## Description

The full\_citation should be in a format similar to that used in a journal article by either cutting and pasting from another document or by typing. Please include author names, title, journal, page numbers, and year or equivalent information for the type of publication given.

The journal status can only be one of:

```
"preparation",
"in press",
"published",
"retracted",
"submitted".
```

The citation type can only be one of:

```
"abstract",
"BMRB only",
"book",
"book chapter",
"internet",
"journal",
"personal communication",
"thesis".
```

The standard journal abbreviation is that defined by the Chemical Abstract Services for the journal where the data are or will be published. If the data in the deposition are related to a J. Biomol. NMR paper, the value must be 'J. Biomol. NMR' to alert the BMRB annotators so that the deposition is properly processed. If the depositor truly does not know the journal, a value of 'not known' or 'na' is acceptable.

## Examples

To add the citation "d'Auvergne E. J., Gooley P. R. (2007). Set theory formulation of the model-free problem and the diffusion seeded model-free paradigm. Mol. Biosyst., 3(7), 483-494.", type:

```
relax> bmr.b.citation(authors=
[["Edward", "d'Auvergne", "E.", "J."],
["Paul", "Gooley", "P.", "R."]], doi=
"10.1039/b702202f", pubmed_id="17579774",
full_citation="d'Auvergne E. J., Gooley P.
R. (2007). Set theory formulation of the
```

```
model-free problem and the diffusion seeded
model-free paradigm. Mol. Biosyst., 3(7),
483-494.", title="Set theory formulation of
the model-free problem and the diffusion
seeded model-free paradigm.", status=
"published", type="journal", journal_abbrev=
"Mol. Biosyst.", journal_full="Molecular
Biosystems", volume=3, issue=7, page_first=
483, page_last=498, year=2007)
```

---

## 10.2.15 bmr.b.display()

### Synopsis

Display the BMRB data in NMR-STAR format.

### Defaults

```
bmr.b.display(self, version=None)
```

---

## 10.2.16 bmr.b.read()

### Synopsis

Read BMRB files in the NMR-STAR format.

### Defaults

```
bmr.b.read(self, file=None, dir=None, version=None,
sample_conditions=None)
```

## Keyword Arguments

**file:** The name of the BMRB STAR formatted file.

**dir:** The directory where the file is located.

**version:** For the reading to use the given NMR-STAR version.

**sample\_conditions:** The sample conditions label in the NMR-STAR file to restrict loading to.

## Description

To search for the results file in the current working directory, set dir to None. Note that only one sample condition can be read per relax data pipe. Therefore if sample\_conditions is not given and multiple conditions exist in the NMR-STAR file, a RelaxError will be raised.

## 10.2.17 bmr.script()

### Synopsis

Specify the scripts used in the analysis.

### Defaults

```
bmr.script(self, file='reduced', dir=None, analysis_type=
None, model_selection=None, engine='relax',
model_elim=False, universal_solution=False)
```

### Keyword Arguments

**file**: The script file name.

**dir**: The directory name.

**analysis\_type**: The type of analysis performed.

**model\_selection**: The model selection technique used, if relevant.

**engine**: The software engine used in the analysis.

**model\_elim**: A model-free specific flag specifying if model elimination was performed.

**universal\_solution**: A model-free specific flag specifying if the universal solution was sought after.

### Description

This user function allows scripts used in the analysis to be included in the BMRB deposition. The following addition information may need to be specified with the script.

The **analysis\_type** must be set. Allowable values include all the data pipe types used in relax, ie:

**'frame\_order'** – The Frame Order theories,

**'jw'** – Reduced spectral density mapping,

**'mf'** – Model-free analysis,

**'N-state'** – N-state model of domain motions,

**'noe'** – Steady state NOE calculation,

**'relax\_fit'** – Relaxation curve fitting,

The **model\_selection** argument only needs to be set if the script selects between different mathematical models. This can be anything, but the following are recommended:

**'AIC'** – Akaike's Information Criteria.

**'AICc'** – Small sample size corrected AIC.

**'BIC'** – Bayesian or Schwarz Information Criteria.

**'Bootstrap'** – Bootstrap model selection.

**'CV'** – Single-item-out cross-validation.

**'Expect'** – The expected overall discrepancy (the true values of the parameters are

**'Farrow'** – Old model-free method by Farrow et al., 1994.

**'Palmer'** – Old model-free method by Mandel et al., 1995.

**'Overall'** – The realised overall discrepancy (the true values of the parameters are

The engine is the software used in the calculation, optimisation, etc. This can be anything, but those recognised by relax (automatic program info, citations, etc. added) include:

**'relax'** – hence relax was used for the full analysis.

**'modelfree4'** – Art Palmer's Modelfree4 program was used for optimising the model-free

**'dasha'** – The Dasha program was used for optimising the model-free parameter values.

**'curvefit'** – Art Palmer's curvefit program was used to determine the  $R_1$  or  $R_2$  values.

The **model\_elim** flag is model-free specific and should be set if the methods from "d'Auvergne, E. J. and Gooley, P. R. (2006). Model-free model elimination: A new step in the model-free dynamic analysis of NMR relaxation data. *J. Biomol. NMR*, 35(2), 117-135." were used. This should be set to True for the full\_analysis.py script.

The **universal\_solution** flag is model-free specific and should be set if the methods from "d'Auvergne E. J., Gooley P. R. (2007). Set theory formulation of the model-free problem and the diffusion seeded model-free paradigm. *Mol. Biosyst.*, 3(7), 483-494." were used. This should be set to True for the full\_analysis.py script.

### Examples

For BMRB deposition, to specify that the full\_analysis.py script was used, type one of:

```
relax> bmr.script('full_analysis.py',
'model-free', 'AIC', 'relax', True, True)
```

```
relax> bmr.script(file='full_analysis.
py', dir=None, analysis_type='model-free',
model_selection='AIC', engine='relax',
model_elim=True, universal_solution=True)
```



### 10.2.18 bmr software()

#### Synopsis

Specify the software used in the analysis.

#### Defaults

**bmr software**(self, name=None, version=None, url=None, vendor\_name=None, cite\_ids=None, tasks=None)

#### Keyword Arguments

**name**: The name of the software program utilised.

**version**: The version of the software, if applicable.

**url**: The web address of the software.

**vendor\_name**: The name of the company or person behind the program.

**cite\_ids**: A list of the citation ID numbers.

**tasks**: A list of all the tasks performed by the software.

#### Description

This user function allows the software used in the analysis to be specified in full detail.

For the tasks list, this should be a python list of strings (eg. ['spectral processing']). Although not restricted to these, the values suggested by the BMRB are:

```
'chemical shift assignment',
'chemical shift calculation',
'collection',
'data analysis',
'geometry optimization',
'peak picking',
'processing',
'refinement',
'structure solution'
```

#### Examples

For BMRB deposition, to say that Sparky was used in the analysis, type:

```
relax> cite_id = bmr.citation(authors=
[['Tom', 'Goddard', 'T.', 'D.'], ['D',
'Kneller', 'D.', 'G.']], title="Goddard, T.
D. and Kneller, D. G., SPARKY 3, University
of California, San Francisco.")
```

```
relax> bmr software('Sparky', version=
'3.110', url="http://www.cgl.ucsf.
edu/home/sparky/", vendor_name="Goddard,
T. D.", cite_ids=[cite_id], tasks=["spectral
analysis"])
```

---

### 10.2.19 bmr software\_select()

#### Synopsis

Select the software used in the analysis.

#### Defaults

**bmr software\_select**(self, name=None, version=None)

#### Keyword Arguments

**name**: The name of the software program utilised.

**version**: The version of the software, if applicable.

#### Description

Rather than specifying all the information directly, this user function allows the software packaged used in the analysis to be selected by name. The programs currently supported are:

**'NMRPipe'** - **http** - //spin.niddk.nih.gov/NMRPipe/

**'Sparky'** - **http** - //www.cgl.ucsf.edu/home/sparky/

More can be added if all relevant information (program name, description, website, original citation, purpose, etc.) is emailed to relax-users@gna.org.

Note that relax is automatically added to the BMRB file.

## Examples

For BMRB deposition, to say that both NMRPipe and Sparky were used prior to relax, type:

```
relax> bmrblib.software_select('NMRPipe')
relax> bmrblib.software_select('Sparky',
version='3.113')
```

---

### 10.2.20 bmrblib.thiol\_state()

#### Synopsis

Select the thiol state of the system.

#### Defaults

**bmrblib.thiol\_state**(self, state='reduced')

#### Keyword Arguments

state: The thiol state.

#### Description

The thiol state can be any text, though the BMRB suggests the following:

```
'all disulfide bound',
'all free',
'all other bound',
'disulfide and other bound',
'free and disulfide bound',
'free and other bound',
'free disulfide and other bound',
'not available',
'not present',
'not reported',
'unknown'.
```

Alternatively the pure states 'reduced' or 'oxidised' could be specified.

## Examples

For BMRB deposition, to say that the protein studied is in the oxidised state, type one of:

```
relax> bmrblib.thiol_state('oxidised')
relax> bmrblib.thiol_state(state='oxidised')
```

---

### 10.2.21 bmrblib.write()

#### Synopsis

Write the results to a BMRB NMR-STAR formatted file.

#### Defaults

**bmrblib.write**(self, file=None, dir='pipe\_name', version=None, force=False)

Keyword Arguments ~~~~~

file: The name of the BMRB file to output results to. Optionally this can be a file object, or any object with a write() method.

dir: The directory name.

version: The NMR-STAR dictionary format version to use.

.sconsign.dblite

**force** – A flag which if True will cause the any pre-existing file to be overwritten.

Description ~~~~~

To place the BMRB file in the current working directory, set dir to None. If dir is set to the special name 'pipe\_name', then the results file will be placed into a directory with the same name as the current data pipe.

---

### 10.2.22 calc()

#### Synopsis

Function for calculating the function value.

## Defaults

`calc(self, verbosity=1)`

## Keyword Arguments

**verbosity:** The amount of information to print to screen. Zero corresponds to minimal output while higher values increase the amount of output. The default value is 1.

---

### 10.2.23 consistency\_tests.set\_frq()

## Synopsis

Function for selecting which relaxation data to use in the consistency tests.

## Defaults

`consistency_tests.set_frq(self, frq=None)`

## Keyword Arguments

**frq:** The spectrometer frequency in Hz.

## Description

This function will select the relaxation data to use in the consistency tests corresponding to the given frequencies.

## Examples

```
relax> consistency_tests.set_frq(600.0 *
1e6)

relax> consistency_tests.set_frq(frq=600.0 *
1e6)
```

---

### 10.2.24 dasha.create()

## Synopsis

Function for creating the Dasha script.

## Defaults

`dasha.create(self, algor='LM', dir=None, force=False)`

## Keyword Arguments

**algor:** The minimisation algorithm.

**dir:** The directory to place the files.

**force:** A flag which if set to True will cause the results file to be overwritten if it already exists.

## Description

The script file created is called '`dir/dasha_script`'.

## Optimisation algorithms

The two minimisation algorithms within Dasha are accessible through the `algor` argument which can be set to:

'LM' - The Levenberg-Marquardt algorithm.

'NR' - Newton-Raphson algorithm.

For Levenberg-Marquardt minimisation, the function '`lmin`' will be called, while for Newton-Raphson, the function '`min`' will be executed.

---

### 10.2.25 dasha.execute()

## Synopsis

Function for executing Dasha.

## Defaults

`dasha.execute(self, dir=None, force=False, binary='dasha')`

## Keyword Arguments

**dir:** The directory to place the files.

**force:** A flag which if set to True will cause the results file to be overwritten if it already exists.

**binary:** The name of the executable Dasha program file.

## Execution

Dasha will be executed as

```
$ dasha < dasha_script | tee dasha_results
```

If you would like to use a different Dasha executable file, change the keyword argument 'binary' to the appropriate file name. If the file is not located within the environment's path, include the full path in front of the binary file name.

---

### 10.2.26 dasha.extract()

#### Synopsis

Function for extracting data from the Dasha results file.

#### Defaults

**dasha.extract**(self, dir=None)

#### Keyword Arguments

**dir**: The directory where the file 'dasha\_results' is found.

---

### 10.2.27 deselect.all()

#### Synopsis

Deselect all spins.

#### Defaults

**deselect.all**(self)

#### Description

This will deselect all spins, irregardless of their current state.

#### Examples

To deselect all spins, simply type:

```
relax> deselect.all()
```

---

### 10.2.28 deselect.read()

#### Synopsis

Deselect the spins contained in a file.

#### Defaults

**deselect.read**(self, file=None, dir=None, spin\_id\_col=None, mol\_name\_col=None, res\_num\_col=None, res\_name\_col=None, spin\_num\_col=None, spin\_name\_col=None, sep=None, spin\_id=None, boolean='AND', change\_all=False)

#### Keyword Arguments

**file**: The name of the file containing the list of spins to deselect.

**dir**: The directory where the file is located.

**spin\_id\_col**: The spin ID string column (an alternative to the mol, res, and spin name and number columns).

**mol\_name\_col**: The molecule name column (alternative to the spin\_id\_col).

**res\_num\_col**: The residue number column (alternative to the spin\_id\_col).

**res\_name\_col**: The residue name column (alternative to the spin\_id\_col).

**spin\_num\_col**: The spin number column (alternative to the spin\_id\_col).

**spin\_name\_col**: The spin name column (alternative to the spin\_id\_col).

**data\_col**: The RDC data column.

**error\_col**: The experimental error column.

**sep**: The column separator (the default is white space).

**spin\_id**: The spin ID string to restrict the loading of data to certain spin subsets.

**boolean**: The boolean operator specifying how spins should be selected.

**change\_all**: A flag specifying if all other spins should be changed.

#### Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the molecule name, residue number, residue name, spin number and/or spin name columns can be supplied allowing this information to be in separate columns. Note

that the numbering of columns starts at one. The spin ID string can be used to restrict the reading to certain spin types, for example only <sup>15</sup>N spins when only residue information is in the file.

Empty lines and lines beginning with a hash are ignored.

The ‘`change_all`’ flag default is `False` meaning that all spins currently either selected or deselected will remain that way. Setting this to `True` will cause all spins not specified in the file to be selected.

## Examples

To deselect all overlapped residues listed with residue numbers in the first column of the file ‘`unresolved`’, type one of:

```
relax> deselect.read('unresolved',
res_num_col=1)
```

```
relax> deselect.read(file='unresolved',
res_num_col=1)
```

To deselect the spins in the second column of the relaxation data file ‘`r1.600`’ while selecting all other spins, for example type:

```
relax> deselect.read('r1.600', spin_num_col=
2, change_all=True)
```

```
relax> deselect.read(file='r1.600',
spin_num_col=2, change_all=True)
```

## Boolean operators

The boolean operator can be used to change how spin systems are selected. The allowed values are: ‘`OR`’, ‘`NOR`’, ‘`AND`’, ‘`NAND`’, ‘`XOR`’, ‘`XNOR`’. The following table details how the selections will occur for the different boolean operators.

(see table [10.1](#))

---

### 10.2.29 deselect.reverse()

#### Synopsis

Reversal of the spin selection for the given spins.

#### Defaults

```
deselect.reverse(self, spin_id=None)
```

#### Keyword Arguments

`spin_id`: The spin ID string.

## Description

By supplying the spin ID string, a subset of spins can have their selection status reversed.

## Examples

To deselect all currently selected spins and select those which are deselected type:

```
relax> deselect.reverse()
```

---

### 10.2.30 deselect.spin()

#### Synopsis

Deselect specific spins.

#### Defaults

```
deselect.spin(self, spin_id=None, change_all=False)
```

#### Keyword Arguments

`spin_id`: The spin ID string.

`change_all`: A flag specifying if all other spins should be changed.

## Description

The ‘`change_all`’ flag default is `False` meaning that all spins currently either selected or deselected will remain that way. Setting this to `True` will cause all spins not specified by the spin ID string to be selected.

## Examples

To deselect all glycines and alanines, type:

```
relax> deselect.spin(spin_id=':GLY|:ALA')
```

To deselect residue 12 MET type:

```
relax> deselect.spin(':12')
```

```
relax> deselect.spin(spin_id=':12')
```

```
relax> deselect.spin(spin_id=':12&:MET')
```

---

Table 10.1: First table for the `deselect.read()` user function.

| Spin system        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|--------------------|---|---|---|---|---|---|---|---|---|
| Original selection | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| New selection      | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| OR                 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| NOR                | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| AND                | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NAND               | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| XOR                | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| XNOR               | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |

### 10.2.31 `diffusion_tensor.copy()`

#### Synopsis

Function for copying diffusion tensor data from one data pipe to another.

#### Defaults

`diffusion_tensor.copy(self, pipe_from=None, pipe_to=None)`

#### Keyword Arguments

**pipe\_from:** The name of the data pipe to copy the diffusion tensor data from.

**pipe\_to:** The name of the data pipe to copy the diffusion tensor data to.

#### Description

This function will copy the diffusion tensor data between data pipes. The destination data pipe must not contain any diffusion tensor data. If the `pipe_from` or `pipe_to` arguments are not supplied, then both will default to the current data pipe (hence giving one argument is essential).

#### Examples

To copy the diffusion tensor from the data pipe 'm1' to the current data pipe, type:

```
relax> diffusion_tensor.copy('m1')
```

```
relax> diffusion_tensor.copy(pipe_from='m1')
```

To copy the diffusion tensor from the current data pipe to the data pipe 'm9', type:

```
relax> diffusion_tensor.copy(pipe_to='m9')
```

To copy the diffusion tensor from the data pipe 'm1' to 'm2', type:

```
relax> diffusion_tensor.copy('m1', 'm2')
```

```
relax> diffusion_tensor.copy(pipe_from='m1', pipe_to='m2')
```

---

### 10.2.32 `diffusion_tensor.delete()`

#### Synopsis

Function for deleting diffusion tensor data.

#### Defaults

`diffusion_tensor.delete(self)`

#### Description

This function will delete all diffusion tensor data from the current data pipe.

---

### 10.2.33 `diffusion_tensor.display()`

#### Synopsis

Function for displaying the diffusion tensor information.

## Defaults

`diffusion_tensor.display(self)`

To select isotropic diffusion, the parameters argument should be a single floating point number. The number is the value of the isotropic global correlation time,  $\tau_m$ , in seconds. To specify the time in nanoseconds, set the 'time\_scale' argument to 1e-9. Alternative parameters can be used by changing the 'param\_types' flag to the following integers

### 10.2.34 diffusion\_tensor.init()

## Synopsis

Function for initialising the diffusion tensor.

0 – {tm} (Default),

1 – {Diso},

where

$$1 / \tau_m = 6\mathfrak{D}_{iso}.$$

## Defaults

`diffusion_tensor.init(self, params=None, time_scale=1.0, d_scale=1.0, angle_units='deg', param_types=0, spheroid_type=None, fixed=True)`

## The spheroid (axially symmetric diffusion)

When two of the three eigenvalues of the diffusion tensor are equal, the molecule diffuses as a spheroid. Four pieces of information are required to specify this tensor, the two geometric parameters,  $\mathfrak{D}_{iso}$  and  $\mathfrak{D}_a$ , and the two orientational parameters, the polar angle  $\theta$  and the azimuthal angle  $\phi$  describing the orientation of the global axis of symmetry. The correlation function of the global diffusion is

## Keyword Arguments

**params:** The diffusion tensor data.

**time\_scale:** The correlation time scaling value.

**d\_scale:** The diffusion tensor eigenvalue scaling value.

**angle\_units:** The units for the angle parameters.

**param\_types:** A flag to select different parameter combinations.

**spheroid\_type:** A string which, if supplied together with spheroid parameters, will restrict the tensor to either being 'oblate' or 'prolate'.

**fixed:** A flag specifying whether the diffusion tensor is fixed or can be optimised.

$$C(\tau) = \frac{1}{5} \sum_{i=-1}^1 \left( \frac{\tau_i}{\tau} \right)^2 e^{-\tau / \tau_i},$$

where

$$c_{-1} = 1/4 (3 \delta_z^2 - 1)^2,$$

$$c_0 = 3 \delta_z^2 (1 - \delta_z^2),$$

$$c_1 = 3/4 (\delta_z^2 - 1)^2,$$

## The sphere (isotropic diffusion)

When the molecule diffuses as a sphere, all three eigenvalues of the diffusion tensor are equal,  $\mathfrak{D}_x = \mathfrak{D}_y = \mathfrak{D}_z$ . In this case, the orientation of the XH bond vector within the diffusion frame is inconsequential to relaxation, hence, the spherical or Euler angles are undefined. Therefore solely a single geometric parameter, either  $\tau_m$  or  $\mathfrak{D}_{iso}$ , can fully and sufficiently parameterise the diffusion tensor. The correlation function for the global rotational diffusion is

and

$$C(\tau) = \frac{1}{5} e^{-\tau / \tau_m},$$

$$1 / \tau_{-1} = 6\mathfrak{D}_{iso} - 2\mathfrak{D}_a,$$

$$1 / \tau_0 = 6\mathfrak{D}_{iso} - \mathfrak{D}_a,$$

$$1 / \tau_1 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a.$$

The direction cosine  $\delta_z$  is defined as the cosine of the angle  $\alpha$  between the XH bond vector and the unique axis of the diffusion tensor.

To select axially symmetric anisotropic diffusion, the parameters argument should be a tuple of floating point numbers of length four. A tuple is a type of data structure enclosed in round brackets, the elements of which are separated by commas. Alternative sets of parameters, ‘param\_types’, are

0 –  $\{\tau_m, \mathfrak{D}_a, \theta, \phi\}$  (Default),

1 –  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \theta, \phi\}$ ,

2 –  $\{\tau_m, \mathfrak{D}_{ratio}, \theta, \phi\}$ ,

3 –  $\{\mathfrak{D}_{\parallel}, \mathfrak{D}_{\perp}, \theta, \phi\}$ ,

4 –  $\{\mathfrak{D}_{iso}, \mathfrak{D}_{ratio}, \theta, \phi\}$ ,

where

$$\tau_m = 1 / 6\mathfrak{D}_{iso},$$

$$\mathfrak{D}_{iso} = 1/3 (\mathfrak{D}_{\parallel} + 2\mathfrak{D}_{\perp}),$$

$$\mathfrak{D}_a = \mathfrak{D}_{\parallel} - \mathfrak{D}_{\perp},$$

$$\mathfrak{D}_{ratio} = \mathfrak{D}_{\parallel} / \mathfrak{D}_{\perp}.$$

The spherical angles  $\{\theta, \phi\}$  orienting the unique axis of the diffusion tensor within the PDB frame are defined between

$$0 \leq \theta \leq \pi,$$

$$0 \leq \phi \leq 2\pi,$$

while the angle  $\alpha$  which is the angle between this axis and the given XH bond vector is defined between

$$0 \leq \alpha \leq 2\pi.$$

The ‘spheroid\_type’ argument should be ‘oblate’, ‘prolate’, or None. The argument will be ignored if the diffusion tensor is not axially symmetric. If ‘oblate’ is given, then the constraint  $\mathfrak{D}_a \leq 0$  is used while if ‘prolate’ is given, then the constraint  $\mathfrak{D}_a \geq 0$  is used. If nothing is supplied, then  $\mathfrak{D}_a$  will be allowed to have any values. To prevent minimisation of diffusion tensor parameters in a space with two minima, it is recommended to specify which tensor is to be minimised, thereby partitioning the two minima into the two subspaces along the boundary  $\mathfrak{D}_a = 0$ .

## The ellipsoid (rhombic diffusion)

When all three eigenvalues of the diffusion tensor are different, the molecule diffuses as an ellipsoid. This diffusion is also known as fully anisotropic, asymmetric, or rhombic. The full tensor is specified by six pieces of information, the three geometric parameters  $\mathfrak{D}_{iso}$ ,  $\mathfrak{D}_a$ , and  $\mathfrak{D}_r$  representing the isotropic, anisotropic, and rhombic components of the tensor, and the three Euler angles  $\alpha$ ,  $\beta$ , and  $\gamma$  orienting the tensor within the PDB frame. The correlation function is

$$C(\tau) = \frac{1}{5} \sum_{i=-2}^2 \frac{\tau_i}{\tau_{iso}} e^{-\tau / \tau_i},$$

where the weights on the exponentials are

$$c_2 = 1/4 (d + e),$$

$$c_1 = 3 \delta_y^2 \delta_z^2,$$

$$c_0 = 3 \delta_x^2 \delta_z^2,$$

$$c_1 = 3 \delta_x^2 \delta_y^2,$$

$$c_2 = 1/4 (d + e).$$

Let

$$\mathfrak{R} = \sqrt{1 + 3\mathfrak{D}_r},$$

then

$$d = 3 (\delta_x^4 + \delta_y^4 + \delta_z^4) - 1,$$

$$e = -1 / \mathfrak{R} ((1 + 3\mathfrak{D}_r)(\delta_x^4 + 2\delta_y^2 \delta_z^2) + (1 - 3\mathfrak{D}_r)(\delta_y^4 + 2\delta_x^2 \delta_z^2) - 2(\delta_z^4 + 2\delta_x^2 \delta_y^2)).$$

The correlation times are

$$1 / \tau_{-2} = 6\mathfrak{D}_{iso} - 2\mathfrak{D}_a \cdot \mathfrak{R},$$

$$1 / \tau_{-1} = 6\mathfrak{D}_{iso} - \mathfrak{D}_a (1 + 3\mathfrak{D}_r),$$

$$1 / \tau_0 = 6\mathfrak{D}_{iso} - \mathfrak{D}_a (1 - 3\mathfrak{D}_r),$$

$$1 / \tau_1 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a,$$



$$1 / \tau_1 = 6\mathfrak{D}_{iso} + 2\mathfrak{D}_a \cdot \mathfrak{R}.$$

The three direction cosines  $\delta_x$ ,  $\delta_y$ , and  $\delta_z$  are the coordinates of a unit vector parallel to the XH bond vector. Hence the unit vector is  $[\delta_x, \delta_y, \delta_z]$ .

To select fully anisotropic diffusion, the parameters argument should be a tuple of length six. A tuple is a type of data structure enclosed in round brackets, the elements of which are separated by commas. Alternative sets of parameters, 'param\_types', are

0 –  $\{\tau_m, \mathfrak{D}_a, \mathfrak{D}_r, \alpha, \beta, \gamma\}$  (Default),

1 –  $\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r, \alpha, \beta, \gamma\}$ ,

2 –  $\{\mathfrak{D}_x, \mathfrak{D}_y, \mathfrak{D}_z, \alpha, \beta, \gamma\}$ ,

3 –  $\{\mathfrak{D}_{xx}, \mathfrak{D}_{yy}, \mathfrak{D}_{zz}, \mathfrak{D}_{xy}, \mathfrak{D}_{xz}, \mathfrak{D}_{yz}\}$ ,

where

$$\tau_m = 1 / 6\mathfrak{D}_{iso},$$

$$\mathfrak{D}_{iso} = 1/3 (\mathfrak{D}_x + \mathfrak{D}_y + \mathfrak{D}_z),$$

$$\mathfrak{D}_a = \mathfrak{D}_z - (\mathfrak{D}_x + \mathfrak{D}_y)/2,$$

$$\mathfrak{D}_r = (\mathfrak{D}_y - \mathfrak{D}_x)/2\mathfrak{D}_a.$$

The angles  $\alpha$ ,  $\beta$ , and  $\gamma$  are the Euler angles describing the diffusion tensor within the PDB frame. These angles are defined using the z-y-z axis rotation notation where  $\alpha$  is the initial rotation angle around the z-axis,  $\beta$  is the rotation angle around the y-axis, and  $\gamma$  is the final rotation around the z-axis again. The angles are defined between

$$0 \leq \alpha \leq 2\pi,$$

$$0 \leq \beta \leq \pi,$$

$$0 \leq \gamma \leq 2\pi.$$

Within the PDB frame, the XH bond vector is described using the spherical angles  $\theta$  and  $\phi$  where  $\theta$  is the polar angle and  $\phi$  is the azimuthal angle defined between

$$0 \leq \theta \leq \pi,$$

$$0 \leq \phi \leq 2\pi.$$

When param\_types is set to 3, then the elements of the diffusion tensor matrix defined within the PDB frame can be supplied.

## Units

The 'time\_scale' argument should be a floating point number. The only parameter affected by this value is  $\tau_m$ .

The 'd\_scale' argument should also be a floating point number. Parameters affected by this value are  $\mathfrak{D}_{iso}$ ,  $\mathfrak{D}_{\parallel}$ ,  $\mathfrak{D}_{\perp}$ ,  $\mathfrak{D}_a$ ,  $\mathfrak{D}_x$ ,  $\mathfrak{D}_y$ , and  $\mathfrak{D}_z$ . Significantly,  $\mathfrak{D}_r$  is not affected.

The 'angle\_units' argument should either be the string 'deg' or 'rad'. Parameters affected are  $\theta$ ,  $\phi$ ,  $\alpha$ ,  $\beta$ , and  $\gamma$ .

## Examples

To set an isotropic diffusion tensor with a correlation time of 10 ns, type:

```
relax> diffusion_tensor.init(10e-9)
relax> diffusion_tensor.init(params=10e-9)
relax> diffusion_tensor.init(10.0, 1e-9)
relax> diffusion_tensor.init(params=10.0,
time_scale=1e-9, fixed=True)
```

To select axially symmetric diffusion with a  $\tau_m$  value of 8.5 ns,  $\mathfrak{D}_{ratio}$  of 1.1,  $\theta$  value of 20 degrees, and  $\phi$  value of 20 degrees, type:

```
relax> diffusion_tensor.init((8.5e-9, 1.1,
20.0, 20.0), param_types=2)
```

To select a spheroid diffusion tensor with a  $\mathfrak{D}_{\parallel}$  value of 1.698e7,  $\mathfrak{D}_{\perp}$  value of 1.417e7,  $\theta$  value of 67.174 degrees, and  $\phi$  value of -83.718 degrees, type one of:

```
relax> diffusion_tensor.init((1.698e7,
1.417e7, 67.174, -83.718), param_types=3)
```

```
relax> diffusion_tensor.init(params=
(1.698e7, 1.417e7, 67.174, -83.718),
param_types=3)
```

```
relax> diffusion_tensor.init((1.698e-1,
1.417e-1, 67.174, -83.718), param_types=
3, d_scale=1e8)
```

```
relax> diffusion_tensor.init(params=(
1.698e-1, 1.417e-1, 67.174, -83.718),
param_types=3, d_scale=1e8)
```

```
relax> diffusion_tensor.init((1.698e-1,
1.417e-1, 1.1724, -1.4612), param_types=
3, d_scale=1e8, angle_units='rad')
```

```
relax> diffusion_tensor.init(params=(
1.698e-1, 1.417e-1, 1.1724, -1.4612),
param_types=3, d_scale=1e8, angle_units=
'rad', fixed=True)
```

To select ellipsoidal diffusion, type:

```
relax> diffusion_tensor.init((1.340e7,
1.516e7, 1.691e7, -82.027, -80.573, 65.568),
param_types=2)
```

### 10.2.35 dx.execute()

#### Synopsis

Execution of OpenDX.

#### Defaults

**dx.execute**(self, file='map', dir='dx', dx\_exe='dx', vp\_exec=True)

#### Keyword Arguments

**file**: The file name prefix. For example if file is set to 'temp', then the OpenDX program temp.net will be loaded.

**dir**: The directory to change to for running OpenDX. If this is set to None, OpenDX will be run in the current directory.

**dx\_exe**: The OpenDX executable file.

**vp\_exec**: A flag specifying whether to execute the visual program automatically at start-up. The default of True causes the program to be executed.

**lower**: The lower bounds of the space. If you wish to change the lower bounds of the map then supply an array of length equal to the number of parameters in the model. A lower bound for each parameter must be supplied. If nothing is supplied then the defaults will be used.

**upper**: The upper bounds of the space. If you wish to change the upper bounds of the map then supply an array of length equal to the number of parameters in the model. An upper bound for each parameter must be supplied. If nothing is supplied then the defaults will be used.

**axis\_incs**: The number of increments or ticks displaying parameter values along the axes of the OpenDX plot.

**file\_prefix**: The file name. All the output files are prefixed with this name. The main file containing the data points will be called the value of 'file'. The OpenDX program will be called 'file.net' and the OpenDX import file will be called 'file.general'.

**dir**: The directory to output files to. Set this to 'None' if you do not want the files to be placed in subdirectory. If the directory does not exist, it will be created.

**point**: An array of parameter values where a point in the map, shown as a red sphere, will be placed. The length must be equal to the number of parameters.

**point\_file**: The name of that the point output files will be prefixed with.

**remap**: A user supplied remapping function. This function will receive the parameter array and must return an array of equal length.

---

### 10.2.36 dx.map()

#### Synopsis

Create a map of the given space in OpenDX format.

#### Defaults

**dx.map**(self, params=None, map\_type='Iso3D', spin\_id=None, inc=20, lower=None, upper=None, axis\_incs=5, file\_prefix='map', dir='dx', point=None, point\_file='point', remap=None)

#### Keyword Arguments

**params**: The parameters to be mapped. This argument should be an array of strings, the meanings of which are described below.

**map\_type**: The type of map to create. For example the default, a 3D isosurface, the type is 'Iso3D'. See below for more details.

**spin\_id**: The spin identification number.

**inc**: The number of increments to map in each dimension. This value controls the resolution of the map.

#### Description

The map type can be changed to one of the following supported map types:

(see table 10.2)

#### Examples

The following commands will generate a map of the extended model-free space for model 'm5' consisting of the parameters  $\{S^2, S_f^2, \tau_s\}$ . Files will be output into the directory 'dx' and will be prefixed by 'map'. In this case, the system is a protein and residue number 6 will be mapped.

```
relax> dx.map(['S2', 'S2f', 'ts'], spin_id=':6')
```

```
relax> dx.map(['S2', 'S2f', 'ts'], spin_id=':6', file_prefix='map', dir='dx')
```

```
relax> dx.map(params=['S2', 'S2f', 'ts'], spin_id=':6', inc=20, file_prefix='map', dir='dx')
```

```
relax> dx.map(params=['S2', 'S2f', 'ts'], spin_id=':6', map_type='Iso3D', inc=20, file_prefix='map', dir='dx')
```

Table 10.2: First table for the `dx.map()` user function.

| Surface type  | Name    |
|---------------|---------|
| 3D isosurface | 'Iso3D' |

To map the model-free space 'm4' for residue 2, spin N6 defined by the parameters  $\{S^2, \tau_e, R_{ex}\}$ , name the results 'test', and to place the files in the current directory, use one of the following commands:

```
relax> dx.map(['S2', 'te', 'Rex'], spin_id=
':2@N6', file_prefix='test', dir=None)
```

```
relax> dx.map(params=['S2', 'te', 'Rex'],
spin_id=':2@N6', inc=100, file_prefix=
'test', dir=None)
```

## Regular expression

The python function 'match', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'[]' – A sequence or set of characters to match to a single character. For example, '[sS]2'

WILL match both 'S2' and 's2'.

'^' – Match the start of the string.

'\$' – Match the end of the string. For example, '^[Ss]2\$' will match 's2' but not 'S2f' or

's2s'.

'.' – Match any character.

'x\*' – Match the character 'x' any number of times, for example 'x' will match, as will 'xxxxx'.

'.\*' – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Diffusion tensor parameter string matching patterns

(see table 10.3)

## Model-free data type string matching patterns

(see table 10.4)

### 10.2.37 eliminate()

#### Synopsis

Elimination or rejection of models.

#### Defaults

**eliminate**(self, function=None, args=None)

#### Keyword Arguments

**function**: A user supplied function for model elimination.

**args**: A tuple of arguments for model elimination.

#### Description

This is used for model validation to eliminate or reject models prior to model selection. Model validation is a part of mathematical modelling whereby models are either accepted or rejected.

Empirical rules are used for model rejection and are listed below. However these can be overridden by supplying a function in the prompt and scripting modes. The function should accept five arguments, a string defining a certain parameter, the value of the parameter, the minimisation instance (ie the residue index if the model is residue specific), and the function arguments. If the model is rejected, the function should return True, otherwise it should return False. The function will be executed multiple times, once for each parameter of the model.

The 'args' keyword argument should be a tuple, a list enclosed in round brackets, and will be passed to the user

Table 10.3: Second table for the `dx.map()` user function.

| Data type                                                                                                       | Object name           | Patterns                                    |
|-----------------------------------------------------------------------------------------------------------------|-----------------------|---------------------------------------------|
| Global correlation time - $\tau_m$                                                                              | <code>'tm'</code>     | <code>'^tm\$'</code>                        |
| Isotropic component of the diffusion tensor - $\mathfrak{D}_{iso}$                                              | <code>'Diso'</code>   | <code>'[Dd]iso'</code>                      |
| Anisotropic component of the diffusion tensor - $\mathfrak{D}_a$                                                | <code>'Da'</code>     | <code>'[Dd]a'</code>                        |
| Rhombic component of the diffusion tensor - $\mathfrak{D}_r$                                                    | <code>'Dr'</code>     | <code>'[Dd]r\$'</code>                      |
| Eigenvalue associated with the x-axis of the diffusion diffusion tensor - $\mathfrak{D}_x$                      | <code>'Dx'</code>     | <code>'[Dd]x'</code>                        |
| Eigenvalue associated with the y-axis of the diffusion diffusion tensor - $\mathfrak{D}_y$                      | <code>'Dy'</code>     | <code>'[Dd]y'</code>                        |
| Eigenvalue associated with the z-axis of the diffusion diffusion tensor - $\mathfrak{D}_z$                      | <code>'Dz'</code>     | <code>'[Dd]z'</code>                        |
| Diffusion coefficient parallel to the major axis of the spheroid diffusion tensor - $\mathfrak{D}_{  }$         | <code>'Dpar'</code>   | <code>'[Dd]par'</code>                      |
| Diffusion coefficient perpendicular to the major axis of the spheroid diffusion tensor - $\mathfrak{D}_{\perp}$ | <code>'Dper'</code>   | <code>'[Dd]per'</code>                      |
| Ratio of the parallel and perpendicular components of the spheroid diffusion tensor - $\mathfrak{D}_{ratio}$    | <code>'Dratio'</code> | <code>'[Dd]ratio'</code>                    |
| The first Euler angle of the ellipsoid diffusion tensor - $\alpha$                                              | <code>'alpha'</code>  | <code>'^a\$'</code> or <code>'alpha'</code> |
| The second Euler angle of the ellipsoid diffusion tensor - $\beta$                                              | <code>'beta'</code>   | <code>'^b\$'</code> or <code>'beta'</code>  |
| The third Euler angle of the ellipsoid diffusion tensor - $\gamma$                                              | <code>'gamma'</code>  | <code>'^g\$'</code> or <code>'gamma'</code> |
| The polar angle defining the major axis of the spheroid diffusion tensor - $\theta$                             | <code>'theta'</code>  | <code>'theta'</code>                        |
| The azimuthal angle defining the major axis of the spheroid diffusion tensor - $\phi$                           | <code>'phi'</code>    | <code>'phi'</code>                          |

Table 10.4: Third table for the `dx.map()` user function.

| Data type                 | Object name                   | Patterns                                                  |
|---------------------------|-------------------------------|-----------------------------------------------------------|
| Local $\tau_m$            | <code>'local_tm'</code>       | <code>'[Ll]ocal[ -_]tm'</code>                            |
| Order parameter $S^2$     | <code>'s2'</code>             | <code>'^[Ss]2\$'</code>                                   |
| Order parameter $S_f^2$   | <code>'s2f'</code>            | <code>'^[Ss]2f\$'</code>                                  |
| Order parameter $S_s^2$   | <code>'s2s'</code>            | <code>'^[Ss]2s\$'</code>                                  |
| Correlation time $\tau_e$ | <code>'te'</code>             | <code>'^te\$'</code>                                      |
| Correlation time $\tau_f$ | <code>'tf'</code>             | <code>'^tf\$'</code>                                      |
| Correlation time $\tau_s$ | <code>'ts'</code>             | <code>'^ts\$'</code>                                      |
| Chemical exchange         | <code>'rex'</code>            | <code>'^[Rr]ex\$' or '[Cc]emical[ -_] [Ee]xchange'</code> |
| Bond length               | <code>'r'</code>              | <code>'^r\$' or '[Bb]ond[ -_] [Ll]ength'</code>           |
| CSA                       | <code>'csa'</code>            | <code>'^[Cc] [Ss] [Aa]\$'</code>                          |
| Heteronucleus type        | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                        |
| Proton type               | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                               |

supplied function or the inbuilt function. For a description of the arguments accepted by the inbuilt functions, see below.

Once a model is rejected, the select flag corresponding to that model will be set to False so that model selection, or any other function, will then skip the model.

### Local $\tau_m$ model elimination rule

The local  $\tau_m$ , in some cases, may exceed the value expected for a global correlation time. Generally the  $\tau_m$  value will be stuck at the upper limit defined for the parameter. These models are eliminated using the rule:

$$\tau_m \geq c$$

The default value of  $c$  is 50 ns, although this can be overridden by supplying the value (in seconds) as the first element of the args tuple.

### Internal correlation times $\{\tau_e, \tau_f, \tau_s\}$ model elimination rules

These parameters may experience the same problem as the local  $\tau_m$  in that the model fails and the parameter value is stuck at the upper limit. These parameters are constrained using the formula ( $\tau_e, \tau_f, \tau_s \leq 2\tau_m$ ). These failed models are eliminated using the rule:

$$\tau_e, \tau_f, \tau_s \geq c \cdot \tau_m$$

The default value of  $c$  is 1.5. Because of round-off errors and the constraint algorithm, setting  $c$  to 2 will result in no models being eliminated as the minimised parameters will always be less than  $2\tau_m$ . The value can be changed by supplying the value as the second element of the tuple.

### Arguments

The `'args'` argument must be a tuple of length 2, the elements of which must be numbers. For example, to eliminate models which have a local  $\tau_m$  value greater than 25 ns and models with internal correlation times greater than 1.5 times  $\tau_m$ , set `'args'` to `(25 * 1e-9, 1.5)`.

## 10.2.38 fix()

### Synopsis

Function for either fixing or allowing parameter values to change during optimisation.

### Defaults

`fix(self, element=None, fixed=True)`

## Keyword Arguments

**element:** Which element to fix.

**fixed:** A flag specifying if the parameters should be fixed or allowed to change.

## Description

The keyword argument ‘**element**’ can be any of the following:

‘**diff**’ - the diffusion tensor parameters. This will allow all diffusion tensor parameters to be toggled.

‘**all\_spins**’ - using this keyword, all parameters from all spins will be toggled.

‘**all**’ - all parameter will be toggled. This is equivalent to combining both ‘**diff**’ and ‘**all\_spins**’.

The flag ‘**fixed**’, if set to True, will fix parameters during optimisation whereas a value of False will allow parameters to vary.

## Description

This function creates a PDB file containing an artificial geometric structure representing the Frame Order cone models.

There are four different types of residue within the PDB. The pivot point is represented as a single carbon atom of the residue ‘**PIV**’. The cone consists of numerous H atoms of the residue ‘**CON**’. The cone axis vector is presented as the residue ‘**AXE**’ with one carbon atom positioned at the pivot and the other  $x$  Å away on the cone axis (set by the size argument). Finally, if Monte Carlo have been performed, there will be multiple ‘**MCC**’ residues representing the cone for each simulation, and multiple ‘**MCA**’ residues representing the multiple cone axes.

To create the diffusion in a cone PDB representation, a uniform distribution of vectors on a sphere is generated using spherical coordinates with the polar angle defined by the cone axis. By incrementing the polar angle using an arccos distribution, a radial array of vectors representing latitude are created while incrementing the azimuthal angle evenly creates the longitudinal vectors. These are all placed into the PDB file as H atoms and are all connected using PDB CONECT records. Each H atom is connected to its two neighbours on the both the longitude and latitude. This creates a geometric PDB object with longitudinal and latitudinal lines representing the filled cone.

### 10.2.39 frame\_order.cone\_pdb()

## Synopsis

Create a PDB file representing the Frame Order cone models.

## Defaults

**frame\_order.cone\_pdb**(self, size=30.0, inc=40, file='cone.pdb', dir=None, force=False)

## Keyword Arguments

**size:** The size of the geometric object in Å.

**inc:** The number of increments used to create the geometric object.

**file:** The name of the PDB file to create.

**dir:** The directory where the file is to be located.

**force:** A flag which, if set to True, will overwrite the any pre-existing file.

### 10.2.40 frame\_order.domain\_to\_pdb()

## Synopsis

Match the domains to PDB files.

## Defaults

**frame\_order.domain\_to\_pdb**(self, domain=None, pdb=None)

## Keyword Arguments

**domain:** The domain to associate the PDB file to.

**pdb:** The PDB file to associate the domain to.

## Description

To display the frame order cone models within Pymol, the two domains need to be associated with PDB files. Then the reference domain will be fixed in the PDB frame, and the moving domain will be rotated to its average position.

## Examples

To set the 'N' domain to the PDB file 'bax\_N\_1J70\_1st.pdb', type one of:

```
relax> frame_order.domain_to_pdb('N',
' bax_N_1J70_1st.pdb')

relax> frame_order.domain_to_pdb(domain='N',
pdb='bax_N_1J70_1st.pdb')
```

## Description

Prior to optimisation of the '2-domain' Frame Order theories, which of the two domains will act as the frame of reference must be specified. This is important for the attachment of cones to domains, etc.

## Examples

To set up the isotropic cone frame order model with 'centre' domain being the frame of reference, type:

```
relax> frame_order.ref_domain(ref='centre')
```

---

### 10.2.41 frame\_order.pivot()

#### Synopsis

Set the pivot point for the two body motion in the structural coordinate system.

#### Defaults

**frame\_order.pivot**(self, pivot=None)

#### Keyword Arguments

**pivot**: The pivot point for the motion (e.g. the position between the 2 domains in PDB coordinates).

#### Examples

To set the pivot point, type one of:

```
relax> frame_order.pivot([12.067, 14.313,
-3.2675])

relax> frame_order.pivot(pivot=[12.067,
14.313, -3.2675])
```

---

### 10.2.43 frame\_order.select\_model()

#### Synopsis

Select and set up the Frame Order model.

#### Defaults

**frame\_order.select\_model**(self, model=None)

#### Keyword Arguments

**model**: The name of the preset Frame Order model.

#### Description

Prior to optimisation, the Frame Order model should be selected. These models consist of three parameter categories:

- The average domain position. This includes the parameters `ave_pos_alpha`, `ave_pos_beta`, and `ave_pos_gamma`. These Euler angles rotate the tensors from the arbitrary PDB frame of the moving domain to the average domain position.
- The frame order eigenframe. This includes the parameters `eigen_alpha`, `eigen_beta`, and `eigen_gamma`. These Euler angles define the major modes of motion. The cone central axis is defined as the z-axis. The pseudo-elliptic cone *x* and *y*-axes are defined as the *x* and *y*-axes of the eigenframe.
- The cone parameters. These are defined as the tilt-torsion angles `cone_theta_x`, `cone_theta_y`, and `cone_sigma_max`. The `cone_theta_x` and `cone_theta_y` parameters define the two cone opening angles of the pseudo-ellipse. The amount

---

### 10.2.42 frame\_order.ref\_domain()

#### Synopsis

Set the reference domain for the '2-domain' Frame Order theories.

#### Defaults

**frame\_order.ref\_domain**(self, ref=None)

#### Keyword Arguments

**ref**: The domain which will act as the frame of reference. This is only valid for the '2-domain' Frame Order theories.

of domain torsion is defined as the average domain position, plus and minus `cone_sigma_max`. The isotropic cones are defined by setting `cone_theta_x = cone_theta_y` and converting the single parameter into a 2<sup>nd</sup> rank order parameter.

The list of available models are:

**'pseudo-ellipse'** - The pseudo-elliptic cone model. This is the full model consisting of the parameters `ave_pos_alpha`, `ave_pos_beta`, `ave_pos_gamma`, `eigen_alpha`, `eigen_beta`, `eigen_gamma`, `cone_theta_x`, `cone_theta_y`, and `cone_sigma_max`.

**'pseudo-ellipse, torsionless'** - The pseudo-elliptic cone with the torsion angle `cone_sigma_max` set to zero.

**'pseudo-ellipse, free rotor'** - The pseudo-elliptic cone with no torsion angle restriction.

**'iso cone'** - The isotropic cone model. The cone is defined by a single order parameter `s1` which is related to the single cone opening angle `cone_theta_x = cone_theta_y`. Due to rotational symmetry about the cone axis, the average position  $\alpha$  Euler angle `ave_pos_alpha` is dropped from the model. The symmetry also collapses the eigenframe to a single z-axis defined by the parameters `axis_theta` and `axis_phi`.

**'iso cone, torsionless'** - The isotropic cone model with the torsion angle `cone_sigma_max` set to zero.

**'iso cone, free rotor'** - The isotropic cone model with no torsion angle restriction.

**'line'** - The line cone model. This is the pseudo-elliptic cone with one of the cone angles, `cone_theta_y`, assumed to be statistically negligible. I.e. the cone angle is so small that it cannot be distinguished from noise.

**'line, torsionless'** - The line cone model with the torsion angle `cone_sigma_max` set to zero.

**'line, free rotor'** - The line cone model with no torsion angle restriction.

**'rotor'** - The only motion is a rotation about the cone axis restricted by the torsion angle `cone_sigma_max`.

**'rigid'** - No domain motions.

**'free rotor'** - The only motion is free rotation about the cone axis.

## Examples

To select the isotropic cone model, type:

```
relax> frame_order.select_model(model='iso
cone')
```

---

### 10.2.44 frq.set()

#### Synopsis

Set the spectrometer frequency of the experiment.

#### Defaults

`frq.set(self, id=None, frq=None)`

#### Keyword arguments

`id`: The experiment identification string.

`frq`: The spectrometer frequency in Hertz.

#### Description

This user function allows the spectrometer frequency of a given experiment to be set.

---

### 10.2.45 grace.view()

#### Synopsis

Visualise the file within Grace.

#### Defaults

`grace.view(self, file=None, dir='grace', grace_exe='xmgrace')`

#### Keyword Arguments

`file`: The name of the file.

`dir`: The directory name.

`grace_exe`: The Grace executable file.



## Description

This can be used to view the specified Grace `*.agr` file by opening it with the Grace program.

## Examples

To view the file `'s2.agr'` in the directory `'grace'`, type:

```
relax> grace.view(file='s2.agr')
relax> grace.view(file='s2.agr', dir=
'grace')
```

The X-axis and Y-axis data type arguments should be plain strings, regular expression is not allowed. If the X-axis data type argument is not given, the plot will default to having the spin sequence along the x-axis. The two axes of the Grace plot can be absolutely any of the data types listed in the tables below. The only limitation, currently anyway, is that the data must belong to the same data pipe.

The spin identification string can be used to limit which spins are used in the plot. The default is that all spins will be used, however, these arguments can be used to select a subset of all spins, or a single spin for plots of Monte Carlo simulations, etc.

The property which is actually plotted can be controlled by the `'plot_data'` argument. It can be one of the following:

---

### 10.2.46 `grace.write()`

## Synopsis

Create a grace `'*.agr'` file.

## Defaults

`grace.write(self, x_data_type='spin', y_data_type=None, spin_id=None, plot_data='value', file=None, dir='grace', force=False, norm=False)`

## Keyword Arguments

`x_data_type`: The data type for the X-axis (no regular expression is allowed).

`y_data_type`: The data type for the Y-axis (no regular expression is allowed).

`spin_id`: The spin identification string.

`plot_data`: The data to use for the plot.

`norm`: Flag for the normalisation of series type data.

`file`: The name of the file.

`dir`: The directory name.

`force`: A flag which, if set to True, will cause the file to be overwritten.

## Description

This is designed to be as flexible as possible so that any combination of data can be plotted. The output is in the format of a Grace plot (also known as ACE/gr, Xmgr, and xmgrace) which only supports two dimensional plots. Three types of keyword arguments can be used to create various types of plot. These include the X-axis and Y-axis data types, the spin identification string, and an argument for selecting what to plot.

`'value'` – Plot values (with errors if they exist).

`'error'` – Plot errors.

`'sims'` – Plot the simulation values.

Normalisation is only allowed for series type data, for example the  $R_2$  exponential curves, and will be ignored for all other data types. If the norm flag is set to True then the y-value of the first point of the series will be set to 1. This normalisation is useful for highlighting errors in the data sets.

## Examples

To write the NOE values for all spins to the Grace file `'noe.agr'`, type one of:

```
relax> grace.write('spin', 'noe', file='noe.
agr')
relax> grace.write(y_data_type='noe', file=
'noe.agr')
relax> grace.write(x_data_type='spin',
y_data_type='noe', file='noe.agr')
relax> grace.write(y_data_type='noe', file=
'noe.agr', force=True)
```

To create a Grace file of `'S2'` vs. `'te'` for all spins, type one of:

```
relax> grace.write('S2', 'te', file='s2_te.
agr')
relax> grace.write(x_data_type='S2',
y_data_type='te', file='s2_te.agr')
relax> grace.write(x_data_type='S2',
y_data_type='te', file='s2_te.agr', force=
True)
```

To create a Grace file of the Monte Carlo simulation values of `'Rex'` vs. `'te'` for residue 123, type one of:

```
relax> grace.write('Rex', 'te', spin_id=
':123', plot_data='sims', file='s2_te.agr')
```

```
relax> grace.write(x_data_type='Rex',
y_data_type='te', spin_id=':123', plot_data=
'sims', file='s2_te.agr')
```

By plotting the peak intensities, the integrity of exponential relaxation curves can be checked and anomalies searched for prior to model-free analysis or reduced spectral density mapping. For example the normalised average peak intensities can be plotted versus the relaxation time periods for the relaxation curves of all residues of a protein. The normalisation, whereby the initial peak intensity of each residue  $I(0)$  is set to 1, emphasises any problems. To produce this Grace file, type:

```
relax> grace.write(x_data_type=
'relax_times', y_data_type='ave_int', file=
'intensities_norm.agr', force=True, norm=
True)
```

## Regular expression

The python function 'match', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'[]' – A sequence or set of characters to match to a single character. For example, '[sS]2'

WILL match both 'S2' and 's2'.

'^' – Match the start of the string.

'\$' – Match the end of the string. For example, '^ [Ss]2\$' will match 's2' but not 'S2f' or

's2s'.

'.' – Match any character.

'x\*' – Match the character 'x' any number of times, for example 'x' will match, as will 'xxxxx'.

'.\*' – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Minimisation statistic data type string matching patterns

(see table 10.5)

## NOE calculation data type string matching patterns

(see table 10.6)

## Relaxation curve fitting data type string matching patterns

(see table 10.7)

## Reduced spectral density mapping data type string matching patterns

(see table 10.8)

## Model-free data type string matching patterns

(see table 10.9)

---

### 10.2.47 grid\_search()

#### Synopsis

The grid search function.

#### Defaults

**grid\_search**(self, lower=None, upper=None, inc=21, constraints=True, verbosity=1)

#### Keyword Arguments

**lower**: An array of the lower bound parameter values for the grid search. The length of the array should be equal to the number of parameters in the model.

**upper**: An array of the upper bound parameter values for the grid search. The length of the array should be equal to the number of parameters in the model.

**inc**: The number of increments to search over. If a single integer is given then the number of increments will be equal in all dimensions. Different numbers of increments in each direction can be set if 'inc' is set to an array of integers of length equal to the number of parameters.

**constraints**: A boolean flag specifying whether the parameters should be constrained. The default is to turn constraints on (constraints=True).

Table 10.5: First table for the `grace.write()` user function.

| Data type             | Object name            | Patterns                                                         |
|-----------------------|------------------------|------------------------------------------------------------------|
| Chi-squared statistic | <code>'chi2'</code>    | <code>'^[Cc]hi2\$'</code> or <code>'^[Cc]hi[-_][Ss]quare'</code> |
| Iteration count       | <code>'iter'</code>    | <code>'^[Ii]ter'</code>                                          |
| Function call count   | <code>'f_count'</code> | <code>'^[Ff].*[-_][Cc]ount'</code>                               |
| Gradient call count   | <code>'g_count'</code> | <code>'^[Gg].*[-_][Cc]ount'</code>                               |
| Hessian call count    | <code>'h_count'</code> | <code>'^[Hh].*[-_][Cc]ount'</code>                               |

Table 10.6: Second table for the `grace.write()` user function.

| Data type           | Object name        | Patterns                                                     |
|---------------------|--------------------|--------------------------------------------------------------|
| Reference intensity | <code>'ref'</code> | <code>'^[Rr]ef\$'</code> or <code>'^[Rr]ef[-_][Ii]nt'</code> |
| Saturated intensity | <code>'sat'</code> | <code>'^[Ss]at\$'</code> or <code>'^[Ss]at[-_][Ii]nt'</code> |
| NOE                 | <code>'noe'</code> | <code>'^[Nn][Oo][Ee]\$'</code>                               |

Table 10.7: Third table for the `grace.write()` user function.

| Data type                        | Object name                | Patterns                               |
|----------------------------------|----------------------------|----------------------------------------|
| Relaxation rate                  | <code>'rx'</code>          | <code>'^[Rr]x\$'</code>                |
| Peak intensities (series)        | <code>'intensities'</code> | <code>'^[Ii]nt\$'</code>               |
| Initial intensity                | <code>'i0'</code>          | <code>'^[Ii]0\$'</code>                |
| Intensity at infinity            | <code>'iinf'</code>        | <code>'^[Ii]inf\$'</code>              |
| Relaxation period times (series) | <code>'relax.times'</code> | <code>'^[Rr]elax[-_][Tt]imes\$'</code> |

Table 10.8: Fourth table for the `grace.write()` user function.

| Data type          | Object name                   | Patterns                                                     |
|--------------------|-------------------------------|--------------------------------------------------------------|
| $J(0)$             | <code>'j0'</code>             | <code>'^[Jj]0\$'</code> or <code>'^[Jj]\(0\)'</code>         |
| $J(\omega_X)$      | <code>'jwx'</code>            | <code>'^[Jj]w[Xx]\$'</code> or <code>'^[Jj]\(w[Xx]\)'</code> |
| $J(\omega_H)$      | <code>'jwh'</code>            | <code>'^[Jj]w[Hh]\$'</code> or <code>'^[Jj]\(w[Hh]\)'</code> |
| Bond length        | <code>'r'</code>              | <code>'^r\$'</code> or <code>'[Bb]ond[-_][Ll]ength'</code>   |
| CSA                | <code>'csa'</code>            | <code>'^[Cc][Ss][Aa]\$'</code>                               |
| Heteronucleus type | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                           |
| Proton type        | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                                  |

Table 10.9: Fifth table for the `grace.write()` user function.

| Data type                 | Object name                   | Patterns                                                              |
|---------------------------|-------------------------------|-----------------------------------------------------------------------|
| Local $\tau_m$            | <code>'local_tm'</code>       | <code>'[Ll]ocal[ -_]tm'</code>                                        |
| Order parameter $S^2$     | <code>'s2'</code>             | <code>'^[Ss]2\$'</code>                                               |
| Order parameter $S_f^2$   | <code>'s2f'</code>            | <code>'^[Ss]2f\$'</code>                                              |
| Order parameter $S_s^2$   | <code>'s2s'</code>            | <code>'^[Ss]2s\$'</code>                                              |
| Correlation time $\tau_e$ | <code>'te'</code>             | <code>'^te\$'</code>                                                  |
| Correlation time $\tau_f$ | <code>'tf'</code>             | <code>'^tf\$'</code>                                                  |
| Correlation time $\tau_s$ | <code>'ts'</code>             | <code>'^ts\$'</code>                                                  |
| Chemical exchange         | <code>'rex'</code>            | <code>'^[Rr]ex\$'</code> or <code>'[Cc]emical[ -_][Ee]xchange'</code> |
| Bond length               | <code>'r'</code>              | <code>'^r\$'</code> or <code>'[Bb]ond[ -_][Ll]ength'</code>           |
| CSA                       | <code>'csa'</code>            | <code>'^[Cc][Ss][Aa]\$'</code>                                        |
| Heteronucleus type        | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                                    |
| Proton type               | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                                           |

**verbosity:** The amount of information to print to screen. Zero corresponds to minimal output while higher values increase the amount of output. The default value is 1.

## Defaults

`intro_on(self, verbose=True)`

### 10.2.48 `intro_off()`

#### Synopsis

Turn the function introductions off.

#### Defaults

`intro_off(self, verbose=True)`

### 10.2.49 `intro_on()`

#### Synopsis

Turn the function introductions on.

### 10.2.50 `jw_mapping.set_freq()`

#### Synopsis

Function for selecting which relaxation data to use in the  $J(\omega)$  mapping.

#### Defaults

`jw_mapping.set_freq(self, freq=None)`

#### Keyword Arguments

`freq`: The spectrometer frequency in Hz.

#### Description

This function will select the relaxation data to use in the reduced spectral density mapping corresponding to the given frequency.

## Examples

```
relax> jw_mapping.set_freq(600.0 * 1e6)
relax> jw_mapping.set_freq(freq=600.0 * 1e6)
```

**verbosity:** The amount of information to print to screen. Zero corresponds to minimal output while higher values increase the amount of output. The default value is 1.

## Diagonal scaling

Diagonal scaling is the transformation of parameter values such that each value has a similar order of magnitude. Certain minimisation techniques, for example the trust region methods, perform extremely poorly with badly scaled problems. In addition, methods which are insensitive to scaling such as Newton minimisation may still benefit due to the minimisation of round off errors.

In Model-free analysis for example, if  $S^2 = 0.5$ ,  $\tau_e = 200$  ps, and  $R_{ex} = 15$  1/s at 600 MHz, the unscaled parameter vector would be [0.5, 2.0e-10, 1.055e-18].  $R_{ex}$  is divided by  $(2 * \pi * 600,000,000)^{**2}$  to make it field strength independent. The scaling vector for this model may be something like [1.0, 1e-9, 1/(2 \*  $\pi$  \* 6e8)\*\*2]. By dividing the unscaled parameter vector by the scaling vector the scaled parameter vector is [0.5, 0.2, 15.0]. To revert to the original unscaled parameter vector, the scaled parameter vector and scaling vector are multiplied.

---

### 10.2.51 minimise()

## Synopsis

Minimisation function.

## Defaults

**minimise(self, \*args, \*\*keywords)**

## Arguments

The arguments, which should all be strings, specify the minimiser as well as its options. A minimum of one argument is required. As this calls the minfx function 'generic\_minimise' the full list of allowed arguments is shown below in the reproduced 'generic\_minimise' docstring. Ignore all sections except those labelled as minimisation algorithms and minimisation options. Also do not select the Method of Multipliers constraint algorithm as this is used in combination with the given minimisation algorithm if the keyword argument 'constraints' is set to 1. The grid search algorithm should also not be selected as this is accessed using the 'grid' function instead. The first argument passed will be set to the minimisation algorithm while all other arguments will be set to the minimisation options.

Keyword arguments differ from normal arguments having the form 'keyword = value'. All arguments must precede keyword arguments in python. For more information see the examples section below or the python tutorial.

## Keyword Arguments

**func\_tol:** The function tolerance. This is used to terminate minimisation once the function value between iterations is less than the tolerance. The default value is 1e-25.

**grad\_tol:** The gradient tolerance. Minimisation is terminated if the current gradient value is less than the tolerance. The default value is None.

**max\_iterations:** The maximum number of iterations. The default value is 1e7.

**constraints:** A boolean flag specifying whether the parameters should be constrained. The default is to turn constraints on (constraints=True).

**scaling:** The diagonal scaling boolean flag. The default that scaling is on (scaling=True).

## Examples

To apply Newton minimisation together with the GMW81 Hessian modification algorithm, the More and Thuente line search algorithm, a function tolerance of 1e-25, no gradient tolerance, a maximum of 10,000,000 iterations, constraints turned on to limit parameter values, and have normal printout, type any combination of:

```
relax> minimise('newton')
relax> minimise('Newton')
relax> minimise('newton', 'gmw')
relax> minimise('newton', 'mt')
relax> minimise('newton', 'gmw', 'mt')
relax> minimise('newton', 'mt', 'gmw')
relax> minimise('newton', func_tol=1e-25)
relax> minimise('newton', func_tol=1e-25,
grad_tol=None)
relax> minimise('newton', max_iter=1e7)
relax> minimise('newton', constraints=True,
max_iter=1e7)
relax> minimise('newton', verbosity=1)
```

To use constrained Simplex minimisation with a maximum of 5000 iterations, type:

```
relax> minimise('simplex', constraints=True,
max_iter=5000)
```

## Note

All the text which follows is a reproduction of the docstring of the generic\_minimise function from the minfx

python package. Only take note of the minimisation algorithms and minimisation options sections, the other sections are not relevant for this function. The Grid search and Method of Multipliers algorithms CANNOT be selected as minimisation algorithms for this function.

The section entitled Keyword Arguments is also completely inaccessible therefore please ignore that text.

Generic minimisation function.

This is a generic function which can be used to access all minimisers using the same set of function arguments. These are the function tolerance value for convergence tests, the maximum number of iterations, a flag specifying which data structures should be returned, and a flag specifying the amount of detail to print to screen.

## Keyword Arguments

**func:** The function which returns the value.

**dfunc:** The function which returns the gradient.

**d2func:** The function which returns the Hessian.

**args:** The tuple of arguments to supply to the functions func, dfunc, and d2func.

**x0:** The vector of initial parameter value estimates (as an array).

**min\_algor:** A string specifying which minimisation technique to use.

**min\_options:** A tuple to pass to the minimisation function as the min\_options keyword.

**func\_tol:** The function tolerance value. Once the function value between iterations decreases below this value, minimisation is terminated.

**grad\_tol:** The gradient tolerance value.

**maxiter:** The maximum number of iterations.

**A:** Linear constraint matrix  $m \times n$  ( $A \cdot x \geq b$ ).

**b:** Linear constraint scalar vector ( $A \cdot x \geq b$ ).

**l:** Lower bound constraint vector ( $l \leq x \leq u$ ).

**u:** Upper bound constraint vector ( $l \leq x \leq u$ ).

**c:** User supplied constraint function.

**dc:** User supplied constraint gradient function.

**d2c:** User supplied constraint Hessian function.

**full\_output:** A flag specifying which data structures should be returned.

**print\_flag:** A flag specifying how much information should be printed to standard output during minimisation. 0 means no output, 1 means minimal output, and values above 1 increase the amount of output printed.

## Minimisation output

The following values of the 'full\_output' flag will return, in tuple form, the following data

0 – 'xk',

1 – '(xk, fk, k, f\_count, g\_count, h\_count, warning)',

where the data names correspond to

'xk' – The array of minimised parameter values,

'fk' – The minimised function value,

'k' – The number of iterations,

'f\_count' – The number of function calls,

'g\_count' – The number of gradient calls,

'h\_count' – The number of Hessian calls,

'warning' – The warning string.

## Minimisation algorithms

A minimisation function is selected if the minimisation algorithm argument, which should be a string, matches a certain pattern. Because the python regular expression 'match' statement is used, various strings can be supplied to select the same minimisation algorithm. Below is a list of the minimisation algorithms available together with the corresponding patterns.

This is a short description of python regular expression, for more information, see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'[]' – A sequence or set of characters to match to a single character. For example, '[Nn]ewton' will match both 'Newton' and 'newton'.

'^' – Match the start of the string.

'\$' – Match the end of the string. For example, '^ [Ll] [Mm] \$' will match 'lm' and 'LM' but will not match if characters are placed either before or after these strings.

To select a minimisation algorithm, set the argument to a string which matches the given pattern.

Unconstrained line search methods:

(see table 10.10)

Unconstrained trust-region methods:

(see table 10.11)

Table 10.10: First table for the minimise() user function.

| Minimisation algorithm            | Patterns                                                                  |
|-----------------------------------|---------------------------------------------------------------------------|
| Back-and-forth coordinate descent | <code>^[Cc][Dd]\$\</code> or <code>^[Cc]oordinate[ _][Dd]escent\$\</code> |
| Steepest descent                  | <code>^[Ss][Dd]\$\</code> or <code>^[Ss]teepest[ _][Dd]escent\$\</code>   |
| Quasi-Newton BFGS                 | <code>^[Bb][Ff][Gg][Ss]\$\</code>                                         |
| Newton                            | <code>^[Nn]ewton\$\</code>                                                |
| Newton-CG                         | <code>^[Nn]ewton[ _][Cc][Gg]\$\</code> or <code>^[Nn][Cc][Gg]\$\</code>   |

Table 10.11: Second table for the minimise() user function.

| Minimisation algorithm | Patterns                                                                 |
|------------------------|--------------------------------------------------------------------------|
| Cauchy point           | <code>^[Cc]auchy\$\</code>                                               |
| Dogleg                 | <code>^[Dd]ogleg\$\</code>                                               |
| CG-Steihaug            | <code>^[Cc][Gg][ _][Ss]teihaug\$\</code> or <code>^[Ss]teihaug\$\</code> |
| Exact trust region     | <code>^[Ee]xact\$\</code>                                                |

Table 10.12: Third table for the minimise() user function.

| Minimisation algorithm | Patterns                                                                 |
|------------------------|--------------------------------------------------------------------------|
| Fletcher-Reeves        | <code>^[Ff][Rr]\$\</code> or <code>^[Ff]letcher[ _][Rr]eeves\$\</code>   |
| Polak-Ribière          | <code>^[Pp][Rr]\$\</code> or <code>^[Pp]olak[ _][Rr]ibiere\$\</code>     |
| Polak-Ribière +        | <code>^[Pp][Rr]\+\$\</code> or <code>^[Pp]olak[ _][Rr]ibiere\+\$\</code> |
| Hestenes-Stiefel       | <code>^[Hh][Ss]\$\</code> or <code>^[Hh]estenes[ _][Ss]tiefel\$\</code>  |

Table 10.13: Fourth table for the minimise() user function.

| Minimisation algorithm | Patterns                                                                |
|------------------------|-------------------------------------------------------------------------|
| Simplex                | <code>^[Ss]implex\$\</code>                                             |
| Levenberg-Marquardt    | <code>^[Ll][Mm]\$\</code> or <code>^[Ll]evenburg-[Mm]arquardt\$\</code> |

Unconstrained conjugate gradient methods:

(see table 10.12)

Miscellaneous unconstrained methods:

(see table 10.13)

Constrained methods:

(see table 10.14)

Global minimisation methods:

(see table 10.15)

## Minimisation options

The minimisation options can be given in any order.

Line search algorithms. These are used in the line search methods and the conjugate gradient methods. The default is the Backtracking line search.

(see table 10.16)

Hessian modifications. These are used in the Newton, Dogleg, and Exact trust region algorithms.

(see table 10.17)

Hessian type, these are used in a few of the trust region methods including the Dogleg and Exact trust region algorithms. In these cases, when the Hessian type is set to Newton, a Hessian modification can also be supplied as above. The default Hessian type is Newton, and the default Hessian modification when Newton is selected is the GMW algorithm.

(see table 10.18)

For Newton minimisation, the default line search algorithm is the More and Thuente line search, while the default Hessian modification is the GMW algorithm.

### 10.2.52 model\_free.create\_model()

#### Synopsis

Function to create a model-free model.

#### Defaults

`model_free.create_model(self, model=None, equation=None, params=None, spin_id=None)`

## Keyword Arguments

**model:** The name of the model-free model.

**equation:** The model-free equation.

**params:** The array of parameter names of the model.

**spin\_id:** The spin identification string.

## Model-free equation

‘**mf\_orig**’ selects the original model-free equations with parameters  $\{S^2, \tau_e\}$ . ‘**mf\_ext**’ selects the extended model-free equations with parameters  $\{S_f^2, \tau_f, S^2, \tau_s\}$ . ‘**mf\_ext2**’ selects the extended model-free equations with parameters  $\{S_f^2, \tau_f, S_s^2, \tau_s\}$ .

## Model-free parameters

The following parameters are accepted for the original model-free equation:

‘**S2**’ – The square of the generalised order parameter.

‘**te**’ – The effective correlation time.

The following parameters are accepted for the extended model-free equation:

‘**S2f**’ – The square of the generalised order parameter of the faster motion.

‘**tf**’ – The effective correlation time of the faster motion.

‘**S2**’ – The square of the generalised order parameter  $S^2 = S_f^2 * S_s^2$ .

‘**ts**’ – The effective correlation time of the slower motion.

The following parameters are accepted for the extended 2 model-free equation:

‘**S2f**’ – The square of the generalised order parameter of the faster motion.

‘**tf**’ – The effective correlation time of the faster motion.

‘**S2s**’ – The square of the generalised order parameter of the slower motion.

‘**ts**’ – The effective correlation time of the slower motion.

The following parameters are accepted for all equations:

‘**Rex**’ – The chemical exchange relaxation.

‘**r**’ – The average bond length  $\langle r \rangle$ .

‘**CSA**’ – The chemical shift anisotropy.



Table 10.14: Fifth table for the minimise() user function.

| Minimisation algorithm | Patterns                                                                    |
|------------------------|-----------------------------------------------------------------------------|
| Method of Multipliers  | <code>^[Mm][Oo][Mm]\$</code> or <code>^[Mm]ethod of [Mm]ultipliers\$</code> |

Table 10.15: Sixth table for the minimise() user function.

| Minimisation algorithm | Patterns                                                              |
|------------------------|-----------------------------------------------------------------------|
| Simulated Annealing    | <code>^[Ss][Aa]\$</code> or <code>^[Ss]imulated [Aa]nnealing\$</code> |

Table 10.16: Seventh table for the minimise() user function.

| Line search algorithm                                      | Patterns                                                                           |
|------------------------------------------------------------|------------------------------------------------------------------------------------|
| Backtracking line search                                   | <code>^[Bb]ack'</code>                                                             |
| Nocedal and Wright interpolation<br>based line search      | <code>^[Nn][Ww][Ii]'</code> or<br><code>^[Nn]ocedal[ ][Ww]right[ ][Ii]nt'</code>   |
| Nocedal and Wright line search<br>for the Wolfe conditions | <code>^[Nn][Ww][Ww]'</code> or<br><code>^[Nn]ocedal[ ][Ww]right[ ][Ww]olfe'</code> |
| More and Thuente line search                               | <code>^[Mm][Tt]'</code> or <code>^[Mm]ore[ ][Tt]huent\$'</code>                    |
| No line search                                             | <code>^[Nn]o [Ll]ine [Ss]earch\$'</code>                                           |

Table 10.17: Eighth table for the minimise() user function.

| Hessian modification                                        | Patterns                               |
|-------------------------------------------------------------|----------------------------------------|
| Unmodified Hessian                                          | <code>^[Nn]o [Hh]essian [Mm]od'</code> |
| Eigenvalue modification                                     | <code>^[Ee]igen'</code>                |
| Cholesky with added multiple of<br>the identity             | <code>^[Cc]hol'</code>                 |
| The Gill, Murray, and Wright<br>modified Cholesky algorithm | <code>^[Gg][Mm][Ww]\$'</code>          |
| The Schnabel and Eskow 1999<br>algorithm                    | <code>^[Ss][Ee]99'</code>              |

Table 10.18: Ninth table for the minimise() user function.

| Hessian type      | Patterns                          |
|-------------------|-----------------------------------|
| Quasi-Newton BFGS | <code>^[Bb][Ff][Gg][Ss]\$'</code> |
| Newton            | <code>^[Nn]ewton\$'</code>        |

## Spin identification string

If ‘`spin_id`’ is supplied then the model will only be created for the corresponding spins. Otherwise the model will be created for all spins.

## Examples

The following commands will create the model-free model ‘`m1`’ which is based on the original model-free equation and contains the single parameter ‘`S2`’.

```
relax> model_free.create_model('m1',
'mf_orig', ['S2'])
relax> model_free.create_model(model='m1',
params=['S2'], equation='mf_orig')
```

The following commands will create the model-free model ‘`large_model`’ which is based on the extended model-free equation and contains the seven parameters ‘`S2f`’, ‘`tf`’, ‘`S2`’, ‘`ts`’, ‘`Rex`’, ‘`CSA`’, ‘`r`’.

```
relax> model_free.create_model('large_model',
'mf_ext', ['S2f', 'tf', 'S2', 'ts', 'Rex',
'CSA', 'r'])
relax> model_free.create_model(model=
'large_model', params=['S2f', 'tf', 'S2',
'ts', 'Rex', 'CSA', 'r'], equation='mf_ext')
```

## Defaults

`model_free.remove_tm(self, spin_id=None)`

## Keyword Arguments

`spin_id`: The spin identification string.

## Description

This function will remove the local  $\tau_m$  parameter from the model-free parameter set. If there is no local  $\tau_m$  parameter within the set nothing will happen.

If no spin identification string is given, then the function will apply to all spins.

## Examples

The following command will remove the parameter ‘`tm`’:

```
relax> model_free.remove_tm()
```

---

### 10.2.53 model\_free.delete()

#### Synopsis

Function for deleting all model-free data from the current data pipe.

#### Defaults

`model_free.delete(self)`

#### Examples

To delete all model-free data, type:

```
relax> model_free.delete()
```

---

### 10.2.55 model\_free.select\_model()

#### Synopsis

Function for the selection of a preset model-free model.

#### Defaults

`model_free.select_model(self, model=None, spin_id=None)`

#### Keyword Arguments

`model`: The name of the preset model.

#### The preset models

The standard preset model-free models are

```
'm0' = {},
'm1' = {S2},
'm2' = {S2,  $\tau_e$ },
'm3' = {S2,  $R_{ex}$ },
'm4' = {S2,  $\tau_e$ ,  $R_{ex}$ },
```

---

### 10.2.54 model\_free.remove\_tm()

#### Synopsis

Function for removing the local  $\tau_m$  parameter from a model.

$$\text{'m5'} = \{S_f^2, S^2, \tau_s\},$$

$$\text{'m6'} = \{S_f^2, \tau_f, S^2, \tau_s\},$$

$$\text{'m7'} = \{S_f^2, S^2, \tau_s, R_{ex}\},$$

$$\text{'m8'} = \{S_f^2, \tau_f, S^2, \tau_s, R_{ex}\},$$

$$\text{'m9'} = \{\text{Rex}\}.$$

The preset model-free models with optimisation of the CSA value are

$$\text{'m10'} = \{\text{CSA}\},$$

$$\text{'m11'} = \{\text{CSA}, S^2\},$$

$$\text{'m12'} = \{\text{CSA}, S^2, \tau_e\},$$

$$\text{'m13'} = \{\text{CSA}, S^2, R_{ex}\},$$

$$\text{'m14'} = \{\text{CSA}, S^2, \tau_e, R_{ex}\},$$

$$\text{'m15'} = \{\text{CSA}, S_f^2, S^2, \tau_s\},$$

$$\text{'m16'} = \{\text{CSA}, S_f^2, \tau_f, S^2, \tau_s\},$$

$$\text{'m17'} = \{\text{CSA}, S_f^2, S^2, \tau_s, R_{ex}\},$$

$$\text{'m18'} = \{\text{CSA}, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\},$$

$$\text{'m19'} = \{\text{CSA}, R_{ex}\}.$$

The preset model-free models with optimisation of the bond length are

$$\text{'m20'} = \{r\},$$

$$\text{'m21'} = \{r, S^2\},$$

$$\text{'m22'} = \{r, S^2, \tau_e\},$$

$$\text{'m23'} = \{r, S^2, R_{ex}\},$$

$$\text{'m24'} = \{r, S^2, \tau_e, R_{ex}\},$$

$$\text{'m25'} = \{r, S_f^2, S^2, \tau_s\},$$

$$\text{'m26'} = \{r, S_f^2, \tau_f, S^2, \tau_s\},$$

$$\text{'m27'} = \{r, S_f^2, S^2, \tau_s, R_{ex}\},$$

$$\text{'m28'} = \{r, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\},$$

$$\text{'m29'} = \{r, \text{CSA}, R_{ex}\}.$$

The preset model-free models with both optimisation of the bond length and CSA are

$$\text{'m30'} = \{r, \text{CSA}\},$$

$$\text{'m31'} = \{r, \text{CSA}, S^2\},$$

$$\text{'m32'} = \{r, \text{CSA}, S^2, \tau_e\},$$

$$\text{'m33'} = \{r, \text{CSA}, S^2, R_{ex}\},$$

$$\text{'m34'} = \{r, \text{CSA}, S^2, \tau_e, R_{ex}\},$$

$$\text{'m35'} = \{r, \text{CSA}, S_f^2, S^2, \tau_s\},$$

$$\text{'m36'} = \{r, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s\},$$

$$\text{'m37'} = \{r, \text{CSA}, S_f^2, S^2, \tau_s, R_{ex}\},$$

$$\text{'m38'} = \{r, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\},$$

$$\text{'m39'} = \{r, \text{CSA}, R_{ex}\}.$$

Warning: The models in the thirties range fail when using standard  $R_1$ ,  $R_2$ , and NOE relaxation data. This is due to the extreme flexibility of these models where a change in the parameter 'r' is compensated by a corresponding change in the parameter 'CSA' and vice versa.

Additional preset model-free models, which are simply extensions of the above models with the addition of a local  $\tau_m$  parameter are:

$$\text{'tm0'} = \{\tau_m\},$$

$$\text{'tm1'} = \{\tau_m, S^2\},$$

$$\text{'tm2'} = \{\tau_m, S^2, \tau_e\},$$

$$\text{'tm3'} = \{\tau_m, S^2, R_{ex}\},$$

$$\text{'tm4'} = \{\tau_m, S^2, \tau_e, R_{ex}\},$$

$$\text{'tm5'} = \{\tau_m, S_f^2, S^2, \tau_s\},$$

$$\text{'tm6'} = \{\tau_m, S_f^2, \tau_f, S^2, \tau_s\},$$

$$\text{'tm7'} = \{\tau_m, S_f^2, S^2, \tau_s, R_{ex}\},$$

$$\text{'tm8'} = \{\tau_m, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\},$$

$$\text{'tm9'} = \{\tau_m, R_{ex}\}.$$

The preset model-free models with optimisation of the CSA value are

$$\text{'tm10'} = \{\tau_m, \text{CSA}\},$$

$$\text{'tm11'} = \{\tau_m, \text{CSA}, S^2\},$$

$$\text{'tm12'} = \{\tau_m, \text{CSA}, S^2, \tau_e\},$$

$$\text{'tm13'} = \{\tau_m, \text{CSA}, S^2, R_{ex}\},$$

$$\text{'tm14'} = \{\tau_m, \text{CSA}, S^2, \tau_e, R_{ex}\},$$

`'tm15'` =  $\{\tau_m, \text{CSA}, S_f^2, S^2, \tau_s\}$ ,  
`'tm16'` =  $\{\tau_m, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s\}$ ,  
`'tm17'` =  $\{\tau_m, \text{CSA}, S_f^2, S^2, \tau_s, R_{ex}\}$ ,  
`'tm18'` =  $\{\tau_m, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\}$ ,  
`'tm19'` =  $\{\tau_m, \text{CSA}, R_{ex}\}$ .

The preset model-free models with optimisation of the bond length are

`'tm20'` =  $\{\tau_m, r\}$ ,  
`'tm21'` =  $\{\tau_m, r, S^2\}$ ,  
`'tm22'` =  $\{\tau_m, r, S^2, \tau_e\}$ ,  
`'tm23'` =  $\{\tau_m, r, S^2, R_{ex}\}$ ,  
`'tm24'` =  $\{\tau_m, r, S^2, \tau_e, R_{ex}\}$ ,  
`'tm25'` =  $\{\tau_m, r, S_f^2, S^2, \tau_s\}$ ,  
`'tm26'` =  $\{\tau_m, r, S_f^2, \tau_f, S^2, \tau_s\}$ ,  
`'tm27'` =  $\{\tau_m, r, S_f^2, S^2, \tau_s, R_{ex}\}$ ,  
`'tm28'` =  $\{\tau_m, r, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\}$ ,  
`'tm29'` =  $\{\tau_m, r, \text{CSA}, R_{ex}\}$ .

The preset model-free models with both optimisation of the bond length and CSA are

`'tm30'` =  $\{\tau_m, r, \text{CSA}\}$ ,  
`'tm31'` =  $\{\tau_m, r, \text{CSA}, S^2\}$ ,  
`'tm32'` =  $\{\tau_m, r, \text{CSA}, S^2, \tau_e\}$ ,  
`'tm33'` =  $\{\tau_m, r, \text{CSA}, S^2, R_{ex}\}$ ,  
`'tm34'` =  $\{\tau_m, r, \text{CSA}, S^2, \tau_e, R_{ex}\}$ ,  
`'tm35'` =  $\{\tau_m, r, \text{CSA}, S_f^2, S^2, \tau_s\}$ ,  
`'tm36'` =  $\{\tau_m, r, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s\}$ ,  
`'tm37'` =  $\{\tau_m, r, \text{CSA}, S_f^2, S^2, \tau_s, R_{ex}\}$ ,  
`'tm38'` =  $\{\tau_m, r, \text{CSA}, S_f^2, \tau_f, S^2, \tau_s, R_{ex}\}$ ,  
`'tm39'` =  $\{\tau_m, r, \text{CSA}, R_{ex}\}$ .

## Spin identification string

If `'spin_id'` is supplied then the model will only be selected for the corresponding spins. Otherwise the model will be selected for all spins.

## Examples

To pick model `'m1'` for all selected spins, type:

```

relax> model_free.select_model('m1')
relax> model_free.select_model(model='m1')
```

---

## 10.2.56 model\_selection()

### Synopsis

Function for model selection.

### Defaults

**model\_selection**(self, method=None, model\_pipe=None, pipes=None)

### Keyword arguments

**method**: The model selection technique (see below).

**model\_pipe**: The name of the new data pipe which will be created by this user function by the copying of the selected data pipe.

**pipes**: An array containing the names of all data pipes to include in model selection.

### Description

The following model selection methods are supported:

**AIC** – Akaike's Information Criteria.

**AICc** – Small sample size corrected AIC.

**BIC** – Bayesian or Schwarz Information Criteria.

**Bootstrap** – Bootstrap model selection.

**CV** – Single-item-out cross-validation.

**Expect** – The expected overall discrepancy (the true values of the parameters are required).

**Farrow** – Old model-free method by Farrow et al., 1994.

**Palmer** – Old model-free method by Mandel et al., 1995.

**Overall** – The realised overall discrepancy (the true values of the parameters are required).

For the methods ‘Bootstrap’, ‘Expect’, and ‘Overall’, the function ‘monte.carlo’ should have previously been executed with the type argument set to the appropriate value to modify its behaviour.

If the pipes argument is not supplied then all data pipes will be used for model selection.

### Example

For model-free analysis, if the preset models 1 to 5 are minimised and loaded into the program, the following commands will carry out AIC model selection and to place the selected results into the ‘mixed’ data pipe, type one of:

```
relax> model_selection('AIC', 'mixed')
relax> model_selection(method='AIC',
modsel_pipe='mixed')
relax> model_selection('AIC', 'mixed',
['m1', 'm2', 'm3', 'm4', 'm5'])
relax> model_selection(method='AIC',
modsel_pipe='mixed', pipes=['m1', 'm2',
'm3', 'm4', 'm5'])
```

---

### 10.2.57 molecule.copy()

#### Synopsis

Copy all data associated with a molecule.

#### Defaults

**molecule.copy**(self, pipe\_from=None, mol\_from=None, pipe\_to=None, mol\_to=None)

#### Keyword Arguments

**pipe\_from**: The data pipe containing the molecule from which the data will be copied. This defaults to the current data pipe.

**mol\_from**: The name of the molecule from which to copy data from.

**pipe\_to**: The data pipe to copy the data to. This defaults to the current data pipe.

**mol\_to**: The name of the new molecule. If left blank, the new molecule will have the same name as the old.

#### Description

This will copy all the data associated with a molecule to a second molecule. This includes all residue and spin system information. The new molecule name must be unique in the destination data pipe.

#### Examples

To copy the molecule data from the molecule ‘GST’ to the new molecule ‘wt-GST’, type:

```
relax> molecule.copy('#GST', '#wt-GST')
relax> molecule.copy(mol_from='#GST',
mol_to='#wt-GST')
```

To copy the molecule data of the molecule ‘Ap4Aase’ from the data pipe ‘m1’ to ‘m2’, assuming the current data pipe is ‘m1’, type:

```
relax> molecule.copy(mol_from='#ApAase',
pipe_to='m2')
relax> molecule.copy(pipe_from='m1',
mol_from='#ApAase', pipe_to='m2', mol_to=
'#ApAase')
```

---

### 10.2.58 molecule.create()

#### Synopsis

Create a new molecule.

#### Defaults

**molecule.create**(self, mol\_name=None, mol\_type=None)

#### Keyword Arguments

**mol\_name**: The name of the new molecule.

**mol\_type**: The type of molecule.

#### Description

This adds a new molecule data container to the relax data storage object. The same molecule name cannot be used more than once. The molecule type need not be specified. However, if given, it should be one of ‘protein’, ‘DNA’, ‘RNA’, ‘organic molecule’, ‘inorganic molecule’, or ‘inorganic molecule’.

## Examples

To create the molecules 'Ap4Aase', 'ATP', and 'MgF4', type:

```
relax> molecule.create('Ap4Aase')
relax> molecule.create('ATP')
relax> molecule.create('MgF4')
```

---

## 10.2.59 molecule.delete()

### Synopsis

Deleting molecules from the relax data store.

### Defaults

**molecule.delete**(self, mol\_id=None)

### Keyword Arguments

mol\_id: The molecule ID string.

### Description

This can be used to delete a single or sets of molecules from the relax data store. The molecule will be deleted from the current data pipe.

### Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '**#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]'**, where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

## 10.2.60 molecule.display()

### Synopsis

Display the molecule information.

### Defaults

**molecule.display**(self, mol\_id=None)

### Keyword Arguments

mol\_id: The molecule ID string.

### Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '**#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]'**, where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

## 10.2.61 molecule.name()

### Synopsis

Name a molecule.

### Defaults

**molecule.name**(self, mol\_id=None, name=None, force=False)

## Keyword Arguments

**mol\_id**: The molecule ID string corresponding to one or more molecules.

**name**: The new molecule name.

**force**: A flag which if True will cause the molecule to be renamed.

## Description

This simply allows molecules to be named (or renamed).

## Examples

To rename the molecule 'Ap4Aase' to 'Inhib Ap4Aase', type one of:

```
relax> molecule.name('#Ap4Aase', 'Inhib
Ap4Aase', True)
```

```
relax> molecule.name(mol_id='#Ap4Aase',
name='Inhib Ap4Aase', force=True)
```

This assumes the molecule 'Ap4Aase' already exists.

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]', where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

## Defaults

**molecule.type**(self, mol\_id=None, type=None, force=False)

## Keyword Arguments

**mol\_id**: The molecule ID string corresponding to one or more molecules.

**type**: The molecule type.

**force**: A flag which if True will cause the molecule to type to be overwritten.

## Description

This allows the type of the molecule to be specified. It can be one of:

```
'protein',
'DNA',
'RNA',
'organic molecule',
'inorganic molecule',
'inorganic molecule'.
```

## Examples

To set the molecule 'Ap4Aase' to the 'protein' type, type one of:

```
relax> molecule.type('#Ap4Aase', 'protein',
True)
```

```
relax> molecule.type(mol_id='#Ap4Aase',
type='protein', force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]', where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can

---

### 10.2.62 molecule.type()

#### Synopsis

Set the molecule type.

be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.63 molmol.clear\_history()

#### Synopsis

Clear the Molmol command history.

#### Defaults

`molmol.clear_history(self)`

#### Description

This will clear the Molmol history from memory.

---

### 10.2.64 molmol.command()

#### Synopsis

Execute a user supplied Molmol command.

#### Defaults

`molmol.command(self, command=None)`

#### Keyword Arguments

`command`: The Molmol command to execute.

#### Description

This allows Molmol commands to be passed to the program. This can be useful for automation or scripting.

#### Examples

To reinitialise the Molmol instance, type:

```
relax> molmol.command("InitAll yes")
```

---

### 10.2.65 molmol.macro\_apply()

#### Synopsis

Execute Molmol macros.

#### Defaults

`molmol.macro_apply(self, data_type=None, style='classic', colour_start=None, colour_end=None, colour_list=None)`

#### Keyword Arguments

`data_type`: The data type to map to the structure.

`style`: The style of the macro.

`colour_start`: The starting colour, either an array or string, of the linear colour gradient.

`colour_end`: The ending colour, either an array or string, of the linear colour gradient.

`colour_list`: The list of colours to match the start and end strings.

#### Description

This allows spin specific values to be mapped to a structure through Molmol macros. Currently only the 'classic' style, which is described below, is available.

#### Examples

To map the order parameter values,  $S^2$ , onto the structure using the classic style, type:

```
relax> molmol.macro_apply('S2')
```

```
relax> molmol.macro_apply(data_type='S2')
```

```
relax> molmol.macro_apply(data_type='S2', style="classic")
```



## Colour

The values are coloured based on a linear colour gradient which is specified through the starting and ending colours. These can either be a string to identify one of the RGB (red, green, blue) colour arrays listed in the tables below, or you can give the RGB vector itself. For example, 'white' and [1.0, 1.0, 1.0] both select the same colour. Leaving both colours unset will select the default colour gradient which for each type of analysis is described below.

When supplying the colours as strings, two lists of colours can be selected from which to match the strings. These are the default Molmol colour list and the X11 colour list, both of which are described in the tables below. The default behaviour is to first search the Molmol list and then the X11 colour list, raising an error if neither contain the name. To explicitly select these lists, set the colour list to either 'molmol' or 'x11'.

## Model-free classic style

Creator: Edward d'Auvergne

Argument string: "classic"

Description: The classic style draws the backbone of a protein in a cylindrical bond style. Rather than colouring the amino acids to which the NH bond belongs, the three covalent bonds of the peptide bond from Ca to Ca in which the NH bond is located are coloured. Deselected residues are shown as black lines.

Supported data types:

(see table [10.19](#))

## Molmol RGB colour arrays

The following table is a list of colours used in Molmol and their corresponding RGB colour values ranging from 0 to 1.

(see table [10.20](#))

## X11 RGB colour arrays

The following table is the list of X11 colour names and their corresponding RGB colour values ranging from 0 to 255.

(see table [10.21](#))

## Defaults

**molmol.macro\_run**(self, file=None, dir='molmol')

## Keyword Arguments

file: The name of the Molmol macro file.

dir: The directory name.

## Description

This user function is for opening and running a Molmol macro located within a text file.

## Examples

To execute the macro file 's2.mac' located in the directory 'molmol', type:

```
relax> molmol.macro_run(file='s2.mac')
relax> molmol.macro_run(file='s2.mac', dir='molmol')
```

---

## 10.2.67 molmol.macro\_write()

### Synopsis

Create Molmol macros.

### Defaults

**molmol.macro\_write**(self, data\_type=None, style='classic', colour\_start=None, colour\_end=None, colour\_list=None, file=None, dir='molmol', force=False)

### Keyword Arguments

data\_type: The data type to map to the structure.

style: The style of the macro.

colour\_start: The starting colour, either an array or string, of the linear colour gradient.

colour\_end: The ending colour, either an array or string, of the linear colour gradient.

colour\_list: The list of colours to match the start and end strings.

file: The name of the file.

dir: The directory name.

force: A flag which, if set to True, will cause the file to be overwritten.

---

## 10.2.66 molmol.macro\_run()

### Synopsis

Open and execute the Molmol macro file.

Table 10.19: First table for the `molmol.macro_apply()` user function.

| Data type                  | String      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $S^2$ .                    | 'S2'        | The standard model-free order parameter, equal to $S_f^2$ . S2s for the two timescale models. The default colour gradient starts at 'yellow' and ends at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                           |
| $S_f^2$ .                  | 'S2f'       | The order parameter of the faster of two internal motions. Residues which are described by model-free models m1 to m4, the single timescale models, are illustrated as white neon bonds. The default colour gradient is the same as that for the $S^2$ data type.                                                                                                                                                                                                                                                                                                         |
| $S_s^2$ .                  | 'S2s'       | The order parameter of the slower of two internal motions. This functions exactly as $S_f^2$ except that $S_s^2$ is plotted instead.                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Amplitude of fast motions. | 'amp_fast'  | Model independent display of the amplit of fast motions. For residues described by model-free models m5 to m8, the value plotted is that of $S_f^2$ . However, for residues described by models m1 to m4, what is shown is dependent on the timescale of the motions. This is because these single timescale models can, at times, be perfect approximations to the more complex two timescale models. Hence if $\tau_e$ is less than 200 ps, $S^2$ is plotted. Otherwise the peptide bond is coloured white. The default colour gradient is the same as that for $S^2$ . |
| Amplitude of slow motions. | 'amp_slow'  | Model independent display of the amplit of slow motions, arbitrarily defined as motions slower than 200 ps. For residues described by model-free models m5 to m8, the order parameter $S^2$ is plotted if $\tau_s > 200$ ps. For models m1 to m4, $S^2$ is plotted if $\tau_e > 200$ ps. The default colour gradient is the same as that for $S^2$ .                                                                                                                                                                                                                      |
| $\tau_e$ .                 | 'te'        | The correlation time, $\tau_e$ . The default colour gradient starts at 'turquoise' and ends at 'blue'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| $\tau_f$ .                 | 'tf'        | The correlation time, $\tau_f$ . The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| $\tau_s$ .                 | 'ts'        | The correlation time, $\tau_s$ . The default colour gradient starts at 'blue' and ends at 'black'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Timescale of fast motions  | 'time_fast' | Model independent display of the timescale of fast motions. For models m5 to m8, only the parameter $\tau_f$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is less than 200 ps. All other residues are assumed to have a correlation time of zero. The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                         |
| Timescale of slow motions  | 'time_slow' | Model independent display of the timescale of slow motions. For models m5 to m8, only the parameter $\tau_s$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is greater than 200 ps. All other residues are coloured white. The default colour gradient is the same as that of $\tau_s$ .                                                                                                                                                                                                                                                  |
| Chemical exchange          | 'Rex'       | The chemical exchange, $R_{ex}$ . Residues which experience no chemical exchange are coloured white. The default colour gradient starts at 'yellow' and finishes at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                |

Table 10.20: Second table for the `molmol.macro_apply()` user function.

| Name           | Red   | Green | Blue  |
|----------------|-------|-------|-------|
| 'black'        | 0.000 | 0.000 | 0.000 |
| 'navy'         | 0.000 | 0.000 | 0.502 |
| 'blue'         | 0.000 | 0.000 | 1.000 |
| 'dark green'   | 0.000 | 0.392 | 0.000 |
| 'green'        | 0.000 | 1.000 | 0.000 |
| 'cyan'         | 0.000 | 1.000 | 1.000 |
| 'turquoise'    | 0.251 | 0.878 | 0.816 |
| 'royal blue'   | 0.255 | 0.412 | 0.882 |
| 'aquamarine'   | 0.498 | 1.000 | 0.831 |
| 'sky green'    | 0.529 | 0.808 | 0.922 |
| 'dark violet'  | 0.580 | 0.000 | 0.827 |
| 'pale green'   | 0.596 | 0.984 | 0.596 |
| 'purple'       | 0.627 | 0.125 | 0.941 |
| 'brown'        | 0.647 | 0.165 | 0.165 |
| 'light blue'   | 0.678 | 0.847 | 0.902 |
| 'grey'         | 0.745 | 0.745 | 0.745 |
| 'light grey'   | 0.827 | 0.827 | 0.827 |
| 'violet'       | 0.933 | 0.510 | 0.933 |
| 'light coral'  | 0.941 | 0.502 | 0.502 |
| 'khaki'        | 0.941 | 0.902 | 0.549 |
| 'beige'        | 0.961 | 0.961 | 0.863 |
| 'red'          | 1.000 | 0.000 | 0.000 |
| 'magenta'      | 1.000 | 0.000 | 1.000 |
| 'deep pink'    | 1.000 | 0.078 | 0.576 |
| 'orange red'   | 1.000 | 0.271 | 0.000 |
| 'hot pink'     | 1.000 | 0.412 | 0.706 |
| 'coral'        | 1.000 | 0.498 | 0.314 |
| 'dark orange'  | 1.000 | 0.549 | 0.000 |
| 'orange'       | 1.000 | 0.647 | 0.000 |
| 'pink'         | 1.000 | 0.753 | 0.796 |
| 'gold'         | 1.000 | 0.843 | 0.000 |
| 'yellow'       | 1.000 | 1.000 | 0.000 |
| 'light yellow' | 1.000 | 1.000 | 0.878 |
| 'ivory'        | 1.000 | 1.000 | 0.941 |
| 'white'        | 1.000 | 1.000 | 1.000 |

Table 10.21: Third table for the `molmol.macro_apply()` user function.

| Name                | Red | Green | Blue |
|---------------------|-----|-------|------|
| snow                | 255 | 250   | 250  |
| ghost white         | 248 | 248   | 255  |
| white smoke         | 245 | 245   | 245  |
| gainsboro           | 220 | 220   | 220  |
| floral white        | 255 | 250   | 240  |
| old lace            | 253 | 245   | 230  |
| linen               | 250 | 240   | 230  |
| antique white       | 250 | 235   | 215  |
| papaya whip         | 255 | 239   | 213  |
| blanched almond     | 255 | 235   | 205  |
| bisque              | 255 | 228   | 196  |
| peach puff          | 255 | 218   | 185  |
| navajo white        | 255 | 222   | 173  |
| moccasin            | 255 | 228   | 181  |
| cornsilk            | 255 | 248   | 220  |
| ivory               | 255 | 255   | 240  |
| lemon chiffon       | 255 | 250   | 205  |
| seashell            | 255 | 245   | 238  |
| honeydew            | 240 | 255   | 240  |
| mint cream          | 245 | 255   | 250  |
| azure               | 240 | 255   | 255  |
| alice blue          | 240 | 248   | 255  |
| lavender            | 230 | 230   | 250  |
| lavender blush      | 255 | 240   | 245  |
| misty rose          | 255 | 228   | 225  |
| white               | 255 | 255   | 255  |
| black               | 0   | 0     | 0    |
| dark slate grey     | 47  | 79    | 79   |
| dim grey            | 105 | 105   | 105  |
| slate grey          | 112 | 128   | 144  |
| light slate grey    | 119 | 136   | 153  |
| grey                | 190 | 190   | 190  |
| light grey          | 211 | 211   | 211  |
| midnight blue       | 25  | 25    | 112  |
| navy                | 0   | 0     | 128  |
| cornflower blue     | 100 | 149   | 237  |
| dark slate blue     | 72  | 61    | 139  |
| slate blue          | 106 | 90    | 205  |
| medium slate blue   | 123 | 104   | 238  |
| light slate blue    | 132 | 112   | 255  |
| medium blue         | 0   | 0     | 205  |
| royal blue          | 65  | 105   | 225  |
| blue                | 0   | 0     | 255  |
| dodger blue         | 30  | 144   | 255  |
| deep sky blue       | 0   | 191   | 255  |
| sky blue            | 135 | 206   | 235  |
| light sky blue      | 135 | 206   | 250  |
| steel blue          | 70  | 130   | 180  |
| light steel blue    | 176 | 196   | 222  |
| light blue          | 173 | 216   | 230  |
| powder blue         | 176 | 224   | 230  |
| pale turquoise      | 175 | 238   | 238  |
| dark turquoise      | 0   | 206   | 209  |
| medium turquoise    | 72  | 209   | 204  |
| turquoise           | 64  | 224   | 208  |
| cyan                | 0   | 255   | 255  |
| light cyan          | 224 | 255   | 255  |
| cadet blue          | 95  | 158   | 160  |
| medium aquamarine   | 102 | 205   | 170  |
| aquamarine          | 127 | 255   | 212  |
| dark green          | 0   | 100   | 0    |
| dark olive green    | 85  | 107   | 47   |
| dark sea green      | 143 | 188   | 143  |
| sea green           | 46  | 139   | 87   |
| medium sea green    | 60  | 179   | 113  |
| light sea green     | 32  | 178   | 170  |
| pale green          | 152 | 251   | 152  |
| spring green        | 0   | 255   | 127  |
| lawn green          | 124 | 252   | 0    |
| green               | 0   | 255   | 0    |
| chartreuse          | 127 | 255   | 0    |
| medium spring green | 0   | 250   | 154  |
| green yellow        | 173 | 255   | 47   |
| lime green          | 50  | 205   | 50   |

## Description

This allows residues specific values to be mapped to a structure through the creation of a Molmol '\*.mac' macro which can be executed in Molmol by clicking on 'File, Macro, Execute User...'. Currently only the 'classic' style, which is described below, is available.

## Molmol RGB colour arrays

The following table is a list of colours used in Molmol and their corresponding RGB colour values ranging from 0 to 1.

(see table 10.23)

## Examples

To create a Molmol macro mapping the order parameter values,  $S^2$ , onto the structure using the classic style, type:

```
relax> molmol.macro_write('S2')
relax> molmol.macro_write(data_type='S2')
relax> molmol.macro_write(data_type='S2',
style="classic", file='s2.mac', dir=
'molmol')
```

## X11 RGB colour arrays

The following table is the list of X11 colour names and their corresponding RGB colour values ranging from 0 to 255.

(see table 10.24)

## Colour

The values are coloured based on a linear colour gradient which is specified through the starting and ending colours. These can either be a string to identify one of the RGB (red, green, blue) colour arrays listed in the tables below, or you can give the RGB vector itself. For example, 'white' and [1.0, 1.0, 1.0] both select the same colour. Leaving both colours unset will select the default colour gradient which for each type of analysis is described below.

When supplying the colours as strings, two lists of colours can be selected from which to match the strings. These are the default Molmol colour list and the X11 colour list, both of which are described in the tables below. The default behaviour is to first search the Molmol list and then the X11 colour list, raising an error if neither contain the name. To explicitly select these lists, set the colour list to either 'molmol' or 'x11'.

## Model-free classic style

Creator: Edward d'Auvergne

Argument string: "classic"

Description: The classic style draws the backbone of a protein in a cylindrical bond style. Rather than colouring the amino acids to which the NH bond belongs, the three covalent bonds of the peptide bond from Ca to Ca in which the NH bond is located are coloured. Deselected residues are shown as black lines.

Supported data types:

(see table 10.22)

Table 10.22: First table for the `molmol.macro_write()` user function.

| Data type                  | String      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $S^2$ .                    | 'S2'        | The standard model-free order parameter, equal to $S_f^2$ . S2s for the two timescale models. The default colour gradient starts at 'yellow' and ends at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                           |
| $S_f^2$ .                  | 'S2f'       | The order parameter of the faster of two internal motions. Residues which are described by model-free models m1 to m4, the single timescale models, are illustrated as white neon bonds. The default colour gradient is the same as that for the $S^2$ data type.                                                                                                                                                                                                                                                                                                         |
| $S_s^2$ .                  | 'S2s'       | The order parameter of the slower of two internal motions. This functions exactly as $S_f^2$ except that $S_s^2$ is plotted instead.                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Amplitude of fast motions. | 'amp_fast'  | Model independent display of the amplit of fast motions. For residues described by model-free models m5 to m8, the value plotted is that of $S_f^2$ . However, for residues described by models m1 to m4, what is shown is dependent on the timescale of the motions. This is because these single timescale models can, at times, be perfect approximations to the more complex two timescale models. Hence if $\tau_e$ is less than 200 ps, $S^2$ is plotted. Otherwise the peptide bond is coloured white. The default colour gradient is the same as that for $S^2$ . |
| Amplitude of slow motions. | 'amp_slow'  | Model independent display of the amplit of slow motions, arbitrarily defined as motions slower than 200 ps. For residues described by model-free models m5 to m8, the order parameter $S^2$ is plotted if $\tau_s > 200$ ps. For models m1 to m4, $S^2$ is plotted if $\tau_e > 200$ ps. The default colour gradient is the same as that for $S^2$ .                                                                                                                                                                                                                      |
| $\tau_e$ .                 | 'te'        | The correlation time, $\tau_e$ . The default colour gradient starts at 'turquoise' and ends at 'blue'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| $\tau_f$ .                 | 'tf'        | The correlation time, $\tau_f$ . The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| $\tau_s$ .                 | 'ts'        | The correlation time, $\tau_s$ . The default colour gradient starts at 'blue' and ends at 'black'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Timescale of fast motions  | 'time_fast' | Model independent display of the timescale of fast motions. For models m5 to m8, only the parameter $\tau_f$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is less than 200 ps. All other residues are assumed to have a correlation zero of zero. The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                         |
| Timescale of slow motions  | 'time_slow' | Model independent display of the timescale of slow motions. For models m5 to m8, only the parameter $\tau_s$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is greater than 200 ps. All other residues are coloured white. The default colour gradient is the same as that of $\tau_s$ .                                                                                                                                                                                                                                                  |
| Chemical exchange          | 'Rex'       | The chemical exchange, $R_{ex}$ . Residues which experience no chemical exchange are coloured white. The default colour gradient starts at 'yellow' and finishes at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                |

Table 10.23: Second table for the molmol.macro\_write() user function.

| Name           | Red   | Green | Blue  |
|----------------|-------|-------|-------|
| 'black'        | 0.000 | 0.000 | 0.000 |
| 'navy'         | 0.000 | 0.000 | 0.502 |
| 'blue'         | 0.000 | 0.000 | 1.000 |
| 'dark green'   | 0.000 | 0.392 | 0.000 |
| 'green'        | 0.000 | 1.000 | 0.000 |
| 'cyan'         | 0.000 | 1.000 | 1.000 |
| 'turquoise'    | 0.251 | 0.878 | 0.816 |
| 'royal blue'   | 0.255 | 0.412 | 0.882 |
| 'aquamarine'   | 0.498 | 1.000 | 0.831 |
| 'sky green'    | 0.529 | 0.808 | 0.922 |
| 'dark violet'  | 0.580 | 0.000 | 0.827 |
| 'pale green'   | 0.596 | 0.984 | 0.596 |
| 'purple'       | 0.627 | 0.125 | 0.941 |
| 'brown'        | 0.647 | 0.165 | 0.165 |
| 'light blue'   | 0.678 | 0.847 | 0.902 |
| 'grey'         | 0.745 | 0.745 | 0.745 |
| 'light grey'   | 0.827 | 0.827 | 0.827 |
| 'violet'       | 0.933 | 0.510 | 0.933 |
| 'light coral'  | 0.941 | 0.502 | 0.502 |
| 'khaki'        | 0.941 | 0.902 | 0.549 |
| 'beige'        | 0.961 | 0.961 | 0.863 |
| 'red'          | 1.000 | 0.000 | 0.000 |
| 'magenta'      | 1.000 | 0.000 | 1.000 |
| 'deep pink'    | 1.000 | 0.078 | 0.576 |
| 'orange red'   | 1.000 | 0.271 | 0.000 |
| 'hot pink'     | 1.000 | 0.412 | 0.706 |
| 'coral'        | 1.000 | 0.498 | 0.314 |
| 'dark orange'  | 1.000 | 0.549 | 0.000 |
| 'orange'       | 1.000 | 0.647 | 0.000 |
| 'pink'         | 1.000 | 0.753 | 0.796 |
| 'gold'         | 1.000 | 0.843 | 0.000 |
| 'yellow'       | 1.000 | 1.000 | 0.000 |
| 'light yellow' | 1.000 | 1.000 | 0.878 |
| 'ivory'        | 1.000 | 1.000 | 0.941 |
| 'white'        | 1.000 | 1.000 | 1.000 |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name              | Red | Green | Blue |
|-------------------|-----|-------|------|
| snow              | 255 | 250   | 250  |
| ghost white       | 248 | 248   | 255  |
| white smoke       | 245 | 245   | 245  |
| gainsboro         | 220 | 220   | 220  |
| floral white      | 255 | 250   | 240  |
| old lace          | 253 | 245   | 230  |
| linen             | 250 | 240   | 230  |
| antique white     | 250 | 235   | 215  |
| papaya whip       | 255 | 239   | 213  |
| blanched almond   | 255 | 235   | 205  |
| bisque            | 255 | 228   | 196  |
| peach puff        | 255 | 218   | 185  |
| navajo white      | 255 | 222   | 173  |
| moccasin          | 255 | 228   | 181  |
| cornsilk          | 255 | 248   | 220  |
| ivory             | 255 | 255   | 240  |
| lemon chiffon     | 255 | 250   | 205  |
| seashell          | 255 | 245   | 238  |
| honeydew          | 240 | 255   | 240  |
| mint cream        | 245 | 255   | 250  |
| azure             | 240 | 255   | 255  |
| alice blue        | 240 | 248   | 255  |
| lavender          | 230 | 230   | 250  |
| lavender blush    | 255 | 240   | 245  |
| misty rose        | 255 | 228   | 225  |
| white             | 255 | 255   | 255  |
| black             | 0   | 0     | 0    |
| dark slate grey   | 47  | 79    | 79   |
| dim grey          | 105 | 105   | 105  |
| slate grey        | 112 | 128   | 144  |
| light slate grey  | 119 | 136   | 153  |
| grey              | 190 | 190   | 190  |
| light grey        | 211 | 211   | 211  |
| midnight blue     | 25  | 25    | 112  |
| navy              | 0   | 0     | 128  |
| cornflower blue   | 100 | 149   | 237  |
| dark slate blue   | 72  | 61    | 139  |
| slate blue        | 106 | 90    | 205  |
| medium slate blue | 123 | 104   | 238  |
| light slate blue  | 132 | 112   | 255  |
| medium blue       | 0   | 0     | 205  |
| royal blue        | 65  | 105   | 225  |
| blue              | 0   | 0     | 255  |
| dodger blue       | 30  | 144   | 255  |
| deep sky blue     | 0   | 191   | 255  |
| sky blue          | 135 | 206   | 235  |
| light sky blue    | 135 | 206   | 250  |
| steel blue        | 70  | 130   | 180  |
| light steel blue  | 176 | 196   | 222  |
| light blue        | 173 | 216   | 230  |
| powder blue       | 176 | 224   | 230  |
| pale turquoise    | 175 | 238   | 238  |
| dark turquoise    | 0   | 206   | 209  |
| medium turquoise  | 72  | 209   | 204  |
| turquoise         | 64  | 224   | 208  |
| cyan              | 0   | 255   | 255  |
| light cyan        | 224 | 255   | 255  |
| cadet blue        | 95  | 158   | 160  |
| medium aquamarine | 102 | 205   | 170  |
| aquamarine        | 127 | 255   | 212  |
| dark green        | 0   | 100   | 0    |
| dark olive green  | 85  | 107   | 47   |
| dark sea green    | 143 | 188   | 143  |
| sea green         | 46  | 139   | 87   |
| medium sea green  | 60  | 179   | 113  |
| light sea green   | 32  | 178   | 170  |



Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name                   | Red | Green | Blue |
|------------------------|-----|-------|------|
| pale green             | 152 | 251   | 152  |
| spring green           | 0   | 255   | 127  |
| lawn green             | 124 | 252   | 0    |
| green                  | 0   | 255   | 0    |
| chartreuse             | 127 | 255   | 0    |
| medium spring green    | 0   | 250   | 154  |
| green yellow           | 173 | 255   | 47   |
| lime green             | 50  | 205   | 50   |
| yellow green           | 154 | 205   | 50   |
| forest green           | 34  | 139   | 34   |
| olive drab             | 107 | 142   | 35   |
| dark khaki             | 189 | 183   | 107  |
| khaki                  | 240 | 230   | 140  |
| pale goldenrod         | 238 | 232   | 170  |
| light goldenrod yellow | 250 | 250   | 210  |
| light yellow           | 255 | 255   | 224  |
| yellow                 | 255 | 255   | 0    |
| gold                   | 255 | 215   | 0    |
| light goldenrod        | 238 | 221   | 130  |
| goldenrod              | 218 | 165   | 32   |
| dark goldenrod         | 184 | 134   | 11   |
| rosy brown             | 188 | 143   | 143  |
| indian red             | 205 | 92    | 92   |
| saddle brown           | 139 | 69    | 19   |
| sienna                 | 160 | 82    | 45   |
| peru                   | 205 | 133   | 63   |
| burlywood              | 222 | 184   | 135  |
| beige                  | 245 | 245   | 220  |
| wheat                  | 245 | 222   | 179  |
| sandy brown            | 244 | 164   | 96   |
| tan                    | 210 | 180   | 140  |
| chocolate              | 210 | 105   | 30   |
| firebrick              | 178 | 34    | 34   |
| brown                  | 165 | 42    | 42   |
| dark salmon            | 233 | 150   | 122  |
| salmon                 | 250 | 128   | 114  |
| light salmon           | 255 | 160   | 122  |
| orange                 | 255 | 165   | 0    |
| dark orange            | 255 | 140   | 0    |
| coral                  | 255 | 127   | 80   |
| light coral            | 240 | 128   | 128  |
| tomato                 | 255 | 99    | 71   |
| orange red             | 255 | 69    | 0    |
| red                    | 255 | 0     | 0    |
| hot pink               | 255 | 105   | 180  |
| deep pink              | 255 | 20    | 147  |
| pink                   | 255 | 192   | 203  |
| light pink             | 255 | 182   | 193  |
| pale violet red        | 219 | 112   | 147  |
| maroon                 | 176 | 48    | 96   |
| medium violet red      | 199 | 21    | 133  |
| violet red             | 208 | 32    | 144  |
| magenta                | 255 | 0     | 255  |
| violet                 | 238 | 130   | 238  |
| plum                   | 221 | 160   | 221  |
| orchid                 | 218 | 112   | 214  |
| medium orchid          | 186 | 85    | 211  |
| dark orchid            | 153 | 50    | 204  |
| dark violet            | 148 | 0     | 211  |
| blue violet            | 138 | 43    | 226  |
| purple                 | 160 | 32    | 240  |
| medium purple          | 147 | 112   | 219  |
| thistle                | 216 | 191   | 216  |
| snow 1                 | 255 | 250   | 250  |
| snow 2                 | 238 | 233   | 233  |
| snow 3                 | 205 | 201   | 201  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name             | Red | Green | Blue |
|------------------|-----|-------|------|
| snow 4           | 139 | 137   | 137  |
| seashell 1       | 255 | 245   | 238  |
| seashell 2       | 238 | 229   | 222  |
| seashell 3       | 205 | 197   | 191  |
| seashell 4       | 139 | 134   | 130  |
| antique white 1  | 255 | 239   | 219  |
| antique white 2  | 238 | 223   | 204  |
| antique white 3  | 205 | 192   | 176  |
| antique white 4  | 139 | 131   | 120  |
| bisque 1         | 255 | 228   | 196  |
| bisque 2         | 238 | 213   | 183  |
| bisque 3         | 205 | 183   | 158  |
| bisque 4         | 139 | 125   | 107  |
| peach puff 1     | 255 | 218   | 185  |
| peach puff 2     | 238 | 203   | 173  |
| peach puff 3     | 205 | 175   | 149  |
| peach puff 4     | 139 | 119   | 101  |
| navajo white 1   | 255 | 222   | 173  |
| navajo white 2   | 238 | 207   | 161  |
| navajo white 3   | 205 | 179   | 139  |
| navajo white 4   | 139 | 121   | 94   |
| lemon chiffon 1  | 255 | 250   | 205  |
| lemon chiffon 2  | 238 | 233   | 191  |
| lemon chiffon 3  | 205 | 201   | 165  |
| lemon chiffon 4  | 139 | 137   | 112  |
| cornsilk 1       | 255 | 248   | 220  |
| cornsilk 2       | 238 | 232   | 205  |
| cornsilk 3       | 205 | 200   | 177  |
| cornsilk 4       | 139 | 136   | 120  |
| ivory 1          | 255 | 255   | 240  |
| ivory 2          | 238 | 238   | 224  |
| ivory 3          | 205 | 205   | 193  |
| ivory 4          | 139 | 139   | 131  |
| honeydew 1       | 240 | 255   | 240  |
| honeydew 2       | 224 | 238   | 224  |
| honeydew 3       | 193 | 205   | 193  |
| honeydew 4       | 131 | 139   | 131  |
| lavender blush 1 | 255 | 240   | 245  |
| lavender blush 2 | 238 | 224   | 229  |
| lavender blush 3 | 205 | 193   | 197  |
| lavender blush 4 | 139 | 131   | 134  |
| misty rose 1     | 255 | 228   | 225  |
| misty rose 2     | 238 | 213   | 210  |
| misty rose 3     | 205 | 183   | 181  |
| misty rose 4     | 139 | 125   | 123  |
| azure 1          | 240 | 255   | 255  |
| azure 2          | 224 | 238   | 238  |
| azure 3          | 193 | 205   | 205  |
| azure 4          | 131 | 139   | 139  |
| slate blue 1     | 131 | 111   | 255  |
| slate blue 2     | 122 | 103   | 238  |
| slate blue 3     | 105 | 89    | 205  |
| slate blue 4     | 71  | 60    | 139  |
| royal blue 1     | 72  | 118   | 255  |
| royal blue 2     | 67  | 110   | 238  |
| royal blue 3     | 58  | 95    | 205  |
| royal blue 4     | 39  | 64    | 139  |
| blue 1           | 0   | 0     | 255  |
| blue 2           | 0   | 0     | 238  |
| blue 3           | 0   | 0     | 205  |
| blue 4           | 0   | 0     | 139  |
| dodger blue 1    | 30  | 144   | 255  |
| dodger blue 2    | 28  | 134   | 238  |
| dodger blue 3    | 24  | 116   | 205  |
| dodger blue 4    | 16  | 78    | 139  |
| steel blue 1     | 99  | 184   | 255  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name               | Red | Green | Blue |
|--------------------|-----|-------|------|
| steel blue 2       | 92  | 172   | 238  |
| steel blue 3       | 79  | 148   | 205  |
| steel blue 4       | 54  | 100   | 139  |
| deep sky blue 1    | 0   | 191   | 255  |
| deep sky blue 2    | 0   | 178   | 238  |
| deep sky blue 3    | 0   | 154   | 205  |
| deep sky blue 4    | 0   | 104   | 139  |
| sky blue 1         | 135 | 206   | 255  |
| sky blue 2         | 126 | 192   | 238  |
| sky blue 3         | 108 | 166   | 205  |
| sky blue 4         | 74  | 112   | 139  |
| light sky blue 1   | 176 | 226   | 255  |
| light sky blue 2   | 164 | 211   | 238  |
| light sky blue 3   | 141 | 182   | 205  |
| light sky blue 4   | 96  | 123   | 139  |
| slate grey 1       | 198 | 226   | 255  |
| slate grey 2       | 185 | 211   | 238  |
| slate grey 3       | 159 | 182   | 205  |
| slate grey 4       | 108 | 123   | 139  |
| light steel blue 1 | 202 | 225   | 255  |
| light steel blue 2 | 188 | 210   | 238  |
| light steel blue 3 | 162 | 181   | 205  |
| light steel blue 4 | 110 | 123   | 139  |
| light blue 1       | 191 | 239   | 255  |
| light blue 2       | 178 | 223   | 238  |
| light blue 3       | 154 | 192   | 205  |
| light blue 4       | 104 | 131   | 139  |
| light cyan 1       | 224 | 255   | 255  |
| light cyan 2       | 209 | 238   | 238  |
| light cyan 3       | 180 | 205   | 205  |
| light cyan 4       | 122 | 139   | 139  |
| pale turquoise 1   | 187 | 255   | 255  |
| pale turquoise 2   | 174 | 238   | 238  |
| pale turquoise 3   | 150 | 205   | 205  |
| pale turquoise 4   | 102 | 139   | 139  |
| cadet blue 1       | 152 | 245   | 255  |
| cadet blue 2       | 142 | 229   | 238  |
| cadet blue 3       | 122 | 197   | 205  |
| cadet blue 4       | 83  | 134   | 139  |
| turquoise 1        | 0   | 245   | 255  |
| turquoise 2        | 0   | 229   | 238  |
| turquoise 3        | 0   | 197   | 205  |
| turquoise 4        | 0   | 134   | 139  |
| cyan 1             | 0   | 255   | 255  |
| cyan 2             | 0   | 238   | 238  |
| cyan 3             | 0   | 205   | 205  |
| cyan 4             | 0   | 139   | 139  |
| dark slate grey 1  | 151 | 255   | 255  |
| dark slate grey 2  | 141 | 238   | 238  |
| dark slate grey 3  | 121 | 205   | 205  |
| dark slate grey 4  | 82  | 139   | 139  |
| aquamarine 1       | 127 | 255   | 212  |
| aquamarine 2       | 118 | 238   | 198  |
| aquamarine 3       | 102 | 205   | 170  |
| aquamarine 4       | 69  | 139   | 116  |
| dark sea green 1   | 193 | 255   | 193  |
| dark sea green 2   | 180 | 238   | 180  |
| dark sea green 3   | 155 | 205   | 155  |
| dark sea green 4   | 105 | 139   | 105  |
| sea green 1        | 84  | 255   | 159  |
| sea green 2        | 78  | 238   | 148  |
| sea green 3        | 67  | 205   | 128  |
| sea green 4        | 46  | 139   | 87   |
| pale green 1       | 154 | 255   | 154  |
| pale green 2       | 144 | 238   | 144  |
| pale green 3       | 124 | 205   | 124  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name               | Red | Green | Blue |
|--------------------|-----|-------|------|
| pale green 4       | 84  | 139   | 84   |
| spring green 1     | 0   | 255   | 127  |
| spring green 2     | 0   | 238   | 118  |
| spring green 3     | 0   | 205   | 102  |
| spring green 4     | 0   | 139   | 69   |
| green 1            | 0   | 255   | 0    |
| green 2            | 0   | 238   | 0    |
| green 3            | 0   | 205   | 0    |
| green 4            | 0   | 139   | 0    |
| chartreuse 1       | 127 | 255   | 0    |
| chartreuse 2       | 118 | 238   | 0    |
| chartreuse 3       | 102 | 205   | 0    |
| chartreuse 4       | 69  | 139   | 0    |
| olive drab 1       | 192 | 255   | 62   |
| olive drab 2       | 179 | 238   | 58   |
| olive drab 3       | 154 | 205   | 50   |
| olive drab 4       | 105 | 139   | 34   |
| dark olive green 1 | 202 | 255   | 112  |
| dark olive green 2 | 188 | 238   | 104  |
| dark olive green 3 | 162 | 205   | 90   |
| dark olive green 4 | 110 | 139   | 61   |
| khaki 1            | 255 | 246   | 143  |
| khaki 2            | 238 | 230   | 133  |
| khaki 3            | 205 | 198   | 115  |
| khaki 4            | 139 | 134   | 78   |
| light goldenrod 1  | 255 | 236   | 139  |
| light goldenrod 2  | 238 | 220   | 130  |
| light goldenrod 3  | 205 | 190   | 112  |
| light goldenrod 4  | 139 | 129   | 76   |
| light yellow 1     | 255 | 255   | 224  |
| light yellow 2     | 238 | 238   | 209  |
| light yellow 3     | 205 | 205   | 180  |
| light yellow 4     | 139 | 139   | 122  |
| yellow 1           | 255 | 255   | 0    |
| yellow 2           | 238 | 238   | 0    |
| yellow 3           | 205 | 205   | 0    |
| yellow 4           | 139 | 139   | 0    |
| gold 1             | 255 | 215   | 0    |
| gold 2             | 238 | 201   | 0    |
| gold 3             | 205 | 173   | 0    |
| gold 4             | 139 | 117   | 0    |
| goldenrod 1        | 255 | 193   | 37   |
| goldenrod 2        | 238 | 180   | 34   |
| goldenrod 3        | 205 | 155   | 29   |
| goldenrod 4        | 139 | 105   | 20   |
| dark goldenrod 1   | 255 | 185   | 15   |
| dark goldenrod 2   | 238 | 173   | 14   |
| dark goldenrod 3   | 205 | 149   | 12   |
| dark goldenrod 4   | 139 | 101   | 8    |
| rosy brown 1       | 255 | 193   | 193  |
| rosy brown 2       | 238 | 180   | 180  |
| rosy brown 3       | 205 | 155   | 155  |
| rosy brown 4       | 139 | 105   | 105  |
| indian red 1       | 255 | 106   | 106  |
| indian red 2       | 238 | 99    | 99   |
| indian red 3       | 205 | 85    | 85   |
| indian red 4       | 139 | 58    | 58   |
| sienna 1           | 255 | 130   | 71   |
| sienna 2           | 238 | 121   | 66   |
| sienna 3           | 205 | 104   | 57   |
| sienna 4           | 139 | 71    | 38   |
| burlywood 1        | 255 | 211   | 155  |
| burlywood 2        | 238 | 197   | 145  |
| burlywood 3        | 205 | 170   | 125  |
| burlywood 4        | 139 | 115   | 85   |
| wheat 1            | 255 | 231   | 186  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name           | Red | Green | Blue |
|----------------|-----|-------|------|
| wheat 2        | 238 | 216   | 174  |
| wheat 3        | 205 | 186   | 150  |
| wheat 4        | 139 | 126   | 102  |
| tan 1          | 255 | 165   | 79   |
| tan 2          | 238 | 154   | 73   |
| tan 3          | 205 | 133   | 63   |
| tan 4          | 139 | 90    | 43   |
| chocolate 1    | 255 | 127   | 36   |
| chocolate 2    | 238 | 118   | 33   |
| chocolate 3    | 205 | 102   | 29   |
| chocolate 4    | 139 | 69    | 19   |
| firebrick 1    | 255 | 48    | 48   |
| firebrick 2    | 238 | 44    | 44   |
| firebrick 3    | 205 | 38    | 38   |
| firebrick 4    | 139 | 26    | 26   |
| brown 1        | 255 | 64    | 64   |
| brown 2        | 238 | 59    | 59   |
| brown 3        | 205 | 51    | 51   |
| brown 4        | 139 | 35    | 35   |
| salmon 1       | 255 | 140   | 105  |
| salmon 2       | 238 | 130   | 98   |
| salmon 3       | 205 | 112   | 84   |
| salmon 4       | 139 | 76    | 57   |
| light salmon 1 | 255 | 160   | 122  |
| light salmon 2 | 238 | 149   | 114  |
| light salmon 3 | 205 | 129   | 98   |
| light salmon 4 | 139 | 87    | 66   |
| orange 1       | 255 | 165   | 0    |
| orange 2       | 238 | 154   | 0    |
| orange 3       | 205 | 133   | 0    |
| orange 4       | 139 | 90    | 0    |
| dark orange 1  | 255 | 127   | 0    |
| dark orange 2  | 238 | 118   | 0    |
| dark orange 3  | 205 | 102   | 0    |
| dark orange 4  | 139 | 69    | 0    |
| coral 1        | 255 | 114   | 86   |
| coral 2        | 238 | 106   | 80   |
| coral 3        | 205 | 91    | 69   |
| coral 4        | 139 | 62    | 47   |
| tomato 1       | 255 | 99    | 71   |
| tomato 2       | 238 | 92    | 66   |
| tomato 3       | 205 | 79    | 57   |
| tomato 4       | 139 | 54    | 38   |
| orange red 1   | 255 | 69    | 0    |
| orange red 2   | 238 | 64    | 0    |
| orange red 3   | 205 | 55    | 0    |
| orange red 4   | 139 | 37    | 0    |
| red 1          | 255 | 0     | 0    |
| red 2          | 238 | 0     | 0    |
| red 3          | 205 | 0     | 0    |
| red 4          | 139 | 0     | 0    |
| deep pink 1    | 255 | 20    | 147  |
| deep pink 2    | 238 | 18    | 137  |
| deep pink 3    | 205 | 16    | 118  |
| deep pink 4    | 139 | 10    | 80   |
| hot pink 1     | 255 | 110   | 180  |
| hot pink 2     | 238 | 106   | 167  |
| hot pink 3     | 205 | 96    | 144  |
| hot pink 4     | 139 | 58    | 98   |
| pink 1         | 255 | 181   | 197  |
| pink 2         | 238 | 169   | 184  |
| pink 3         | 205 | 145   | 158  |
| pink 4         | 139 | 99    | 108  |
| light pink 1   | 255 | 174   | 185  |
| light pink 2   | 238 | 162   | 173  |
| light pink 3   | 205 | 140   | 149  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name              | Red | Green | Blue |
|-------------------|-----|-------|------|
| light pink 4      | 139 | 95    | 101  |
| pale violet red 1 | 255 | 130   | 171  |
| pale violet red 2 | 238 | 121   | 159  |
| pale violet red 3 | 205 | 104   | 137  |
| pale violet red 4 | 139 | 71    | 93   |
| maroon 1          | 255 | 52    | 179  |
| maroon 2          | 238 | 48    | 167  |
| maroon 3          | 205 | 41    | 144  |
| maroon 4          | 139 | 28    | 98   |
| violet red 1      | 255 | 62    | 150  |
| violet red 2      | 238 | 58    | 140  |
| violet red 3      | 205 | 50    | 120  |
| violet red 4      | 139 | 34    | 82   |
| magenta 1         | 255 | 0     | 255  |
| magenta 2         | 238 | 0     | 238  |
| magenta 3         | 205 | 0     | 205  |
| magenta 4         | 139 | 0     | 139  |
| orchid 1          | 255 | 131   | 250  |
| orchid 2          | 238 | 122   | 233  |
| orchid 3          | 205 | 105   | 201  |
| orchid 4          | 139 | 71    | 137  |
| plum 1            | 255 | 187   | 255  |
| plum 2            | 238 | 174   | 238  |
| plum 3            | 205 | 150   | 205  |
| plum 4            | 139 | 102   | 139  |
| medium orchid 1   | 224 | 102   | 255  |
| medium orchid 2   | 209 | 95    | 238  |
| medium orchid 3   | 180 | 82    | 205  |
| medium orchid 4   | 122 | 55    | 139  |
| dark orchid 1     | 191 | 62    | 255  |
| dark orchid 2     | 178 | 58    | 238  |
| dark orchid 3     | 154 | 50    | 205  |
| dark orchid 4     | 104 | 34    | 139  |
| purple 1          | 155 | 48    | 255  |
| purple 2          | 145 | 44    | 238  |
| purple 3          | 125 | 38    | 205  |
| purple 4          | 85  | 26    | 139  |
| medium purple 1   | 171 | 130   | 255  |
| medium purple 2   | 159 | 121   | 238  |
| medium purple 3   | 137 | 104   | 205  |
| medium purple 4   | 93  | 71    | 139  |
| thistle 1         | 255 | 225   | 255  |
| thistle 2         | 238 | 210   | 238  |
| thistle 3         | 205 | 181   | 205  |
| thistle 4         | 139 | 123   | 139  |
| grey 0            | 0   | 0     | 0    |
| grey 1            | 3   | 3     | 3    |
| grey 2            | 5   | 5     | 5    |
| grey 3            | 8   | 8     | 8    |
| grey 4            | 10  | 10    | 10   |
| grey 5            | 13  | 13    | 13   |
| grey 6            | 15  | 15    | 15   |
| grey 7            | 18  | 18    | 18   |
| grey 8            | 20  | 20    | 20   |
| grey 9            | 23  | 23    | 23   |
| grey 10           | 26  | 26    | 26   |
| grey 11           | 28  | 28    | 28   |
| grey 12           | 31  | 31    | 31   |
| grey 13           | 33  | 33    | 33   |
| grey 14           | 36  | 36    | 36   |
| grey 15           | 38  | 38    | 38   |
| grey 16           | 41  | 41    | 41   |
| grey 17           | 43  | 43    | 43   |
| grey 18           | 46  | 46    | 46   |
| grey 19           | 48  | 48    | 48   |
| grey 20           | 51  | 51    | 51   |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name    | Red | Green | Blue |
|---------|-----|-------|------|
| grey 21 | 54  | 54    | 54   |
| grey 22 | 56  | 56    | 56   |
| grey 23 | 59  | 59    | 59   |
| grey 24 | 61  | 61    | 61   |
| grey 25 | 64  | 64    | 64   |
| grey 26 | 66  | 66    | 66   |
| grey 27 | 69  | 69    | 69   |
| grey 28 | 71  | 71    | 71   |
| grey 29 | 74  | 74    | 74   |
| grey 30 | 77  | 77    | 77   |
| grey 31 | 79  | 79    | 79   |
| grey 32 | 82  | 82    | 82   |
| grey 33 | 84  | 84    | 84   |
| grey 34 | 87  | 87    | 87   |
| grey 35 | 89  | 89    | 89   |
| grey 36 | 92  | 92    | 92   |
| grey 37 | 94  | 94    | 94   |
| grey 38 | 97  | 97    | 97   |
| grey 39 | 99  | 99    | 99   |
| grey 40 | 102 | 102   | 102  |
| grey 41 | 105 | 105   | 105  |
| grey 42 | 107 | 107   | 107  |
| grey 43 | 110 | 110   | 110  |
| grey 44 | 112 | 112   | 112  |
| grey 45 | 115 | 115   | 115  |
| grey 46 | 117 | 117   | 117  |
| grey 47 | 120 | 120   | 120  |
| grey 48 | 122 | 122   | 122  |
| grey 49 | 125 | 125   | 125  |
| grey 50 | 127 | 127   | 127  |
| grey 51 | 130 | 130   | 130  |
| grey 52 | 133 | 133   | 133  |
| grey 53 | 135 | 135   | 135  |
| grey 54 | 138 | 138   | 138  |
| grey 55 | 140 | 140   | 140  |
| grey 56 | 143 | 143   | 143  |
| grey 57 | 145 | 145   | 145  |
| grey 58 | 148 | 148   | 148  |
| grey 59 | 150 | 150   | 150  |
| grey 60 | 153 | 153   | 153  |
| grey 61 | 156 | 156   | 156  |
| grey 62 | 158 | 158   | 158  |
| grey 63 | 161 | 161   | 161  |
| grey 64 | 163 | 163   | 163  |
| grey 65 | 166 | 166   | 166  |
| grey 66 | 168 | 168   | 168  |
| grey 67 | 171 | 171   | 171  |
| grey 68 | 173 | 173   | 173  |
| grey 69 | 176 | 176   | 176  |
| grey 70 | 179 | 179   | 179  |
| grey 71 | 181 | 181   | 181  |
| grey 72 | 184 | 184   | 184  |
| grey 73 | 186 | 186   | 186  |
| grey 74 | 189 | 189   | 189  |
| grey 75 | 191 | 191   | 191  |
| grey 76 | 194 | 194   | 194  |
| grey 77 | 196 | 196   | 196  |
| grey 78 | 199 | 199   | 199  |
| grey 79 | 201 | 201   | 201  |
| grey 80 | 204 | 204   | 204  |
| grey 81 | 207 | 207   | 207  |
| grey 82 | 209 | 209   | 209  |
| grey 83 | 212 | 212   | 212  |
| grey 84 | 214 | 214   | 214  |
| grey 85 | 217 | 217   | 217  |
| grey 86 | 219 | 219   | 219  |

Table 10.24: Third table for the `molmol.macro_write()` user function.

| Name         | Red | Green | Blue |
|--------------|-----|-------|------|
| grey 87      | 222 | 222   | 222  |
| grey 88      | 224 | 224   | 224  |
| grey 89      | 227 | 227   | 227  |
| grey 90      | 229 | 229   | 229  |
| grey 91      | 232 | 232   | 232  |
| grey 92      | 235 | 235   | 235  |
| grey 93      | 237 | 237   | 237  |
| grey 94      | 240 | 240   | 240  |
| grey 95      | 242 | 242   | 242  |
| grey 96      | 245 | 245   | 245  |
| grey 97      | 247 | 247   | 247  |
| grey 98      | 250 | 250   | 250  |
| grey 99      | 252 | 252   | 252  |
| grey 100     | 255 | 255   | 255  |
| dark grey    | 169 | 169   | 169  |
| dark blue    | 0   | 0     | 139  |
| dark cyan    | 0   | 139   | 139  |
| dark magenta | 139 | 0     | 139  |
| dark red     | 139 | 0     | 0    |
| light green  | 144 | 238   | 144  |



---

## 10.2.68 molmol.ribbon()

### Synopsis

Apply the Molmol ribbon style.

### Defaults

**molmol.ribbon(self)**

### Description

This applies the Molmol ribbon style which is equivalent to clicking on ‘ribbon’ in the Molmol side menu. To do this, the following commands are executed:

```
CalcAtom ‘H’
CalcAtom ‘HN’
CalcSecondary
XMacStand ribbon.mac
```

### Examples

To apply the ribbon style to the PDB file loaded, type:

```
relax> molmol.ribbon()
```

### Description

In executing this user function, a PDB file must have previously been loaded, a geometric object or polygon representing the Brownian rotational diffusion tensor will be overlain with the loaded PDB file and displayed within Molmol. The PDB file containing the geometric object must be created using the complementary structure.create\_diff\_tensor\_pdb user function.

To display the diffusion tensor, the multiple commands will be executed. To overlay the structure with the diffusion tensor, everything will be selected and reoriented and moved to their original PDB frame positions:

```
SelectAtom ‘
SelectBond ‘
SelectAngle ‘
SelectDist ‘
SelectPrim ‘
RotateInit
MoveInit
```

Next the tensor PDB file is read in, selected, and the covalent bonds of the PDB CONECT records calculated:

```
ReadPdb file
SelectMol ‘@file’
CalcBond 1 1 1
```

---

## 10.2.69 molmol.tensor\_pdb()

### Synopsis

Display the diffusion tensor PDB geometric object over the loaded PDB.

### Defaults

**molmol.tensor\_pdb(self, file=None)**

### Keyword Arguments

file: The name of the PDB file containing the tensor geometric object.

Then only the atoms and bonds of the geometric object are selected and the ‘ball/stick’ style applied:

```
SelectAtom ‘O’
SelectBond ‘O’
SelectAtom ‘:TNS’
SelectBond ‘:TNS’
XMacStand ball_stick.mac
```

The appearance is finally touched up:

```
RadiusAtom 1
SelectAtom ‘:TNS@C*’
```

RadiusAtom 1.5

---

### 10.2.70 `molmol.view()`

#### Synopsis

View the collection of molecules from the loaded PDB file.

#### Defaults

`molmol.view(self)`

#### Description

This will simply launch Molmol.

#### Examples

```
relax> molmol.view()
```

---

### 10.2.71 `monte_carlo.create_data()`

#### Synopsis

Function for creating simulation data.

#### Defaults

`monte_carlo.create_data(self, method='back_calc')`

#### Keyword Arguments

`method`: The simulation method.

#### Description

The `method` argument can either be set to `'back_calc'` or `'direct'`, the choice of which determines the simulation type. If the values or parameters are calculated rather than minimised, this option will have no effect, hence, `'back_calc'` and `'direct'` are identical.

For error analysis, the `method` argument should be set to `'back_calc'` which will result in proper Monte Carlo

simulations. The data used for each simulation is back calculated from the minimised model parameters and is randomised using Gaussian noise where the standard deviation is from the original error set. When the method is set to `'back_calc'`, this function should only be called after the model is fully minimised.

The simulation type can be changed by setting the `method` argument to `'direct'`. This will result in simulations which cannot be used in error analysis and which are no longer Monte Carlo simulations. However, these simulations are required for certain model selection techniques (see the documentation for the model selection function for details), and can be used for other purposes. Rather than the data being back calculated from the fitted model parameters, the data is generated by taking the original data and randomising using Gaussian noise with the standard deviations set to the original error set.

#### Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

1. The measured data set together with the corresponding error set should be loaded into `relax`.
2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.
3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.
4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.
5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).
6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.
7. Failed simulations are removed using the techniques of model elimination.
8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the

functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```
relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step 5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step 8.
```

An example for reduced spectral density mapping is:

```
relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step 8.
```

---

### 10.2.72 monte\_carlo.error\_analysis()

#### Synopsis

Function for calculating parameter errors from the Monte Carlo simulations.

#### Defaults

`monte_carlo.error_analysis(self, prune=0.0)`

#### Keyword Arguments

`prune`: Legacy argument corresponding to 'trim' in Art Palmer's Modelfree program.

#### Description

Parameter errors are calculated as the standard deviation of the distribution of parameter values. This function should never be used if parameter values are obtained by minimisation and the simulation data are generated using the method 'direct'. The reason is because only true Monte Carlo simulations can give the true parameter errors.

The `prune` argument is legacy code which corresponds to the 'trim' option in Art Palmer's Modelfree program. To remove failed simulations, the `eliminate` function should be used prior to this function. Eliminating the simulations specifically identifies and removes the failed simulations whereas the `prune` argument will only, in a few cases, positively identify failed simulations but only if severe parameter limits have been imposed. Most failed models will pass through the pruning process and hence cause a catastrophic increase in the parameter errors. If the argument must be used, the following must be taken into account. If the values or parameters are calculated rather than minimised, the `prune` argument must be set to zero. The value of this argument is proportional to the number of simulations removed prior to error calculation. If `prune` is set to 0.0, all simulations are used for calculating errors, whereas a value of 1.0 excludes all data. In almost all cases `prune` must be set to zero, any value greater than zero will result in an underestimation of the error values. If a value is supplied, the lower and upper tails of the distribution of chi-squared values will be excluded from the error calculation.

#### Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

1. The measured data set together with the corresponding error set should be loaded into `relax`.
2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.
3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.
4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.
5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).

6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.

7. Failed simulations are removed using the techniques of model elimination.

8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```
relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step 5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step 8.
```

An example for reduced spectral density mapping is:

```
relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step 8.
```

---

### 10.2.73 monte\_carlo.initial\_values()

#### Synopsis

Function for setting the initial simulation parameter values.

#### Defaults

`monte_carlo.initial_values(self)`

#### Description

This function only effects where minimisation occurs and can therefore be skipped if the values or parameters are calculated rather than minimised. However, if accidentally run in this case, the results will be unaffected. It should only be called after the model or run is fully minimised. Once called, the functions 'grid\_search' and 'minimise' will only effect the simulations and not the model parameters.

The initial values of the parameters for each simulation is set to the minimised parameters of the model. A grid search can be undertaken for each simulation instead, although this is computationally expensive and unnecessary. The minimisation function should be executed for a second time after running this function.

#### Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

1. The measured data set together with the corresponding error set should be loaded into relax.
2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.
3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.
4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.
5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).

6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.

7. Failed simulations are removed using the techniques of model elimination.

8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```
relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step 5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step 8.
```

An example for reduced spectral density mapping is:

```
relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step 8.
```

1. The measured data set together with the corresponding error set should be loaded into relax.

2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.

3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.

4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.

5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).

6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.

7. Failed simulations are removed using the techniques of model elimination.

8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```
relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step 5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step 8.
```

An example for reduced spectral density mapping is:

### 10.2.74 monte\_carlo.off()

#### Synopsis

Function for turning simulations off.

#### Defaults

**monte\_carlo.off(self)**

#### Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

```

relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step
3.
relax> monte_carlo.create_data(method=
'back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step
8.

```

---

### 10.2.75 monte\_carlo.on()

#### Synopsis

Function for turning simulations on.

#### Defaults

**monte\_carlo.on(self)**

#### Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

1. The measured data set together with the corresponding error set should be loaded into relax.
2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.
3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.
4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.
5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).
6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.

7. Failed simulations are removed using the techniques of model elimination.

8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```

relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step
3.
relax> monte_carlo.create_data(method=
'back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step
5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step
8.

```

An example for reduced spectral density mapping is:

```

relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step
3.
relax> monte_carlo.create_data(method=
'back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step
8.

```

---

### 10.2.76 monte\_carlo.setup()

#### Synopsis

Function for setting up Monte Carlo simulations.

#### Defaults

**monte\_carlo.setup(self, number=500)**



## Keyword Arguments

**number:** The number of Monte Carlo simulations.

## Description

This function must be called prior to any of the other Monte Carlo functions. The effect is that the number of simulations will be set and that simulations will be turned on.

## Monte Carlo Simulation Overview

For proper error analysis using Monte Carlo simulations, a sequence of function calls is required for running the various simulation components. The steps necessary for implementing Monte Carlo simulations are:

1. The measured data set together with the corresponding error set should be loaded into relax.
2. Either minimisation is used to optimise the parameters of the chosen model, or a calculation is run.
3. To initialise and turn on Monte Carlo simulations, the number of simulations,  $n$ , needs to be set.
4. The simulation data needs to be created either by back calculation from the fully minimised model parameters from step 2 or by direct calculation when values are calculated rather than minimised. The error set is used to randomise each simulation data set by assuming Gaussian errors. This creates a synthetic data set for each Monte Carlo simulation.
5. Prior to minimisation of the parameters of each simulation, initial parameter estimates are required. These are taken as the optimised model parameters. An alternative is to use a grid search for each simulation to generate initial estimates, however this is extremely computationally expensive. For the case where values are calculated rather than minimised, this step should be skipped (although the results will be unaffected if this is accidentally run).
6. Each simulation requires minimisation or calculation. The same techniques as used in step 2, excluding the grid search when minimising, should be used for the simulations.
7. Failed simulations are removed using the techniques of model elimination.
8. The model parameter errors are calculated from the distribution of simulation parameters.

Monte Carlo simulations can be turned on or off using functions within this class. Once the function for setting up simulations has been called, simulations will be turned on. The effect of having simulations turned on is that the functions used for minimisation (grid search, minimise, etc) or calculation will only affect the simulation parameters and not the model parameters. By subsequently turning simulations off using the appropriate function, the functions used in minimisation will affect the model parameters and not the simulation parameters.

An example, for model-free analysis, which includes only the functions required for implementing the above steps is:

```
relax> grid_search(inc=11) # Step 2.
relax> minimise('newton') # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> monte_carlo.initial_values() # Step 5.
relax> minimise('newton') # Step 6.
relax> eliminate() # Step 7.
relax> monte_carlo.error_analysis() # Step 8.
```

An example for reduced spectral density mapping is:

```
relax> calc() # Step 2.
relax> monte_carlo.setup(number=500) # Step 3.
relax> monte_carlo.create_data(method='back_calc') # Step 4.
relax> calc() # Step 6.
relax> monte_carlo.error_analysis() # Step 8.
```

---

## 10.2.77 n\_state\_model.CoM()

### Synopsis

Centre of mass (CoM) analysis.

### Defaults

**n\_state\_model.CoM**(self, pivot\_point=[0.0, 0.0, 0.0], centre=None)

## Keyword Arguments

**pivot\_point:** The pivot point of the motions between the two domains.

**centre:** The optional argument for manually specifying the CoM of the initial position prior to the  $N$  rotations to the positions of the  $N$  states.

## Description

This function is used for analysing the domain motion information content of the N states from the N-state model. The states do not correspond to physical states, hence nothing can be extracted from the individual states. This analysis involves the calculation of the pivot to centre of mass (pivot-CoM) order parameter and subsequent cone of motions.

For the analysis, both the pivot point and centre of mass must be specified. The supplied pivot point must be a vector of floating point numbers of length 3. If the centre keyword argument is supplied, it must also be a vector of floating point numbers (of length 3). If the centre argument is not supplied, then the CoM will be calculated from the selected parts of a previously loaded structure.

## Examples

To perform an analysis where the pivot is at the origin and the CoM is set to the N-terminal domain of a previously loaded PDB file (the C-terminal domain has been deselected), type:

```
relax> n_state_model.CoM()
```

To perform an analysis where the pivot is at the origin (because the real pivot has been shifted to this position) and the CoM is at the position [0, 0, 1], type one of:

```
relax> n_state_model.CoM(centre=[0, 0, 1])
```

```
relax> n_state_model.CoM(centre=[0.0, 0.0, 1.0])
```

```
relax> n_state_model.CoM(pivot_point=[0.0, 0.0, 0.0], centre=[0.0, 0.0, 1.0])
```

dir: The directory where the file is located.

force: A flag which, if set to True, will overwrite the any pre-existing file.

## Description

This function creates a PDB file containing an artificial geometric structure to represent the various cone models. These models include:

'diff in cone'

'diff on cone'

The model can be selected by setting the cone\_type argument to one of these strings. The cone is represented as an isotropic cone with its axis parallel to the average pivot-CoM vector, the vertex placed at the pivot point of the domain motions, and the length of the edge of the cone equal to the pivot-CoM distance multiplied by the scaling argument. The resultant PDB file can subsequently read into any molecular viewer.

There are four different types of residue within the PDB. The pivot point is represented as a single carbon atom of the residue 'PIV'. The cone consists of numerous H atoms of the residue 'CON'. The average pivot-CoM vector is presented as the residue 'AVE' with one carbon atom positioned at the pivot and the other at the head of the vector (after scaling by the scale argument). Finally, if Monte Carlo have been performed, there will be multiple 'MCC' residues representing the cone for each simulation, and multiple 'MCA' residues representing the varying average pivot-CoM vector for each simulation.

To create the diffusion in a cone PDB representation, a uniform distribution of vectors on a sphere is generated using spherical coordinates with the polar angle defined from the average pivot-CoM vector. By incrementing the polar angle using an arccos distribution, a radial array of vectors representing latitude are created while incrementing the azimuthal angle evenly creates the longitudinal vectors. These are all placed into the PDB file as H atoms and are all connected using PDB CONECT records. Each H atom is connected to its two neighbours on the both the longitude and latitude. This creates a geometric PDB object with longitudinal and latitudinal lines representing the filled cone.

---

### 10.2.78 n\_state\_model.cone\_pdb()

#### Synopsis

Create a PDB file representing the cone models from the centre of mass (CoM) analysis.

#### Defaults

```
n_state_model.cone_pdb(self, cone_type=None, scale=1.0,
file='cone.pdb', dir=None, force=False)
```

#### Keyword Arguments

cone\_type: The type of cone model to represent.

scale: Value for scaling the pivot-CoM distance which the size of the cone defaults to.

file: The name of the PDB file.

---

### 10.2.79 n\_state\_model.elim\_no\_prob()

#### Synopsis

Eliminate the structures or states with no probability.



## Defaults

`n_state_model.elim_no_prob(self)`

## Examples

Simply type:

```
relax> n_state_model.elim_no_prob(N=8)
```

---

### 10.2.80 `n_state_model.number_of_states()`

## Synopsis

Set the number of states in the N-state model.

## Defaults

`n_state_model.number_of_states(self, N=None)`

## Keyword Arguments

N: The number of states.

## Description

Prior to optimisation, the number of states in the N-state model can be specified. If the number of states is not set, then this parameter will be equal to the number of loaded structures.

## Examples

To set up an 8-state model, type:

```
relax> n_state_model.number_of_states(N=8)
```

---

### 10.2.81 `n_state_model.ref_domain()`

## Synopsis

Set the reference domain for the ‘2-domain’ N-state model.

## Defaults

`n_state_model.ref_domain(self, ref=None)`

## Keyword Arguments

ref: The domain which will act as the frame of reference. This is only valid for the ‘2-domain’ N-state model.

## Description

Prior to optimisation of the ‘2-domain’ N-state model, which of the two domains will act as the frame of reference must be specified. The N-states will be rotations of the other domain, so to switch the frame of reference to the other domain simply transpose the rotation matrices.

## Examples

To set up a 5-state model with ‘C’ domain being the frame of reference, type:

```
relax> n_state_model.ref_domain(ref='C')
```

---

### 10.2.82 `n_state_model.select_model()`

## Synopsis

Select the N-state model type and set up the model.

## Defaults

`n_state_model.select_model(self, model=None)`

## Keyword Arguments

model: The name of the preset N-state model.

## Description

Prior to optimisation, the N-state model type should be selected. The preset models are:

‘2-domain’ - The N-state model for a system of two domains, where one domain experiences a reduced tensor.

‘population’ - The N-state model whereby only populations are optimised. The structures loaded into relax are assumed to be fixed. I.e. if two domains are present, the Euler angles for each state are fixed. The parameters of the model include the weight or probability for each

state and the alignment tensor - {p0, p1, ..., pN, Axx, Ayy, Axy, Axz, Ayz}.

**'fixed'** - The N-state model whereby all motions are fixed and all populations are fixed to the set probabilities. The parameters of the model are simply the alignment tensor, {Axx, Ayy, Axy, Axz, Ayz}.

## Examples

To analyse populations of states, type:

```
relax> n_state_model.select_model(model=
'populations')
```

---

### 10.2.83 noe.read\_restraints()

#### Synopsis

Read NOESY or ROESY restraints from a file.

#### Defaults

```
noe.read_restraints(self, file=None, dir=None,
proton1_col=None, proton2_col=None, lower_col=None,
upper_col=None, sep=None)
```

#### Keyword Arguments

**file:** The name of the file containing the restraint data.

**dir:** The directory where the file is located.

**proton1\_col:** The column containing the first proton of the NOE or ROE cross peak.

**proton2\_col:** The column containing the second proton of the NOE or ROE cross peak.

**lower\_col:** The column containing the lower NOE bound.

**upper\_col:** The column containing the upper NOE bound.

**sep:** The column separator (the default is white space).

#### Description

The format of the file will be automatically determined, for example Xplor formatted restraint files. A generically formatted file is also supported if it contains minimally four columns with the two proton names and the upper and lower bounds, as specified by the column numbers. The proton names need to be in the spin ID string format.

## Examples

To read the Xplor formatted restraint file 'NOE.xpl', type one of:

```
relax> noe.read_restraints('NOE.xpl')
relax> noe.read_restraints(file='NOE.xpl')
```

To read the generic formatted file 'noes', type one of:

```
relax> noe.read_restraints(file='NOE.xpl',
proton1_col=0, proton2_col=1, lower_col=2,
upper_col=3)
```

---

### 10.2.84 noe.spectrum\_type()

#### Synopsis

Set the steady-state NOE spectrum type for pre-loaded peak intensities.

#### Defaults

```
noe.spectrum_type(self, spectrum_type=None,
spectrum_id=None)
```

#### Keyword Arguments

**spectrum\_type:** The type of steady-state NOE spectrum, one of 'ref' for the reference spectrum or 'sat' for the saturated spectrum.

**spectrum\_id:** The spectrum ID string.

#### Description

The spectrum type can be one of the following:

The steady-state NOE reference spectrum.

The steady-state NOE spectrum with proton saturation turned on.

Peak intensities should be loaded before this user function via the spectrum.read\_intensities user function. The intensity values will then be associated with a spectrum ID string which can be used here.

---

### 10.2.85 palmer.create()

#### Synopsis

Function for creating the Modelfree4 input files.

#### Defaults

```
palmer.create(self, dir=None, force=False, binary=
'modelfree4', diff_search='none', sims=0, sim_type='pred',
trim=0, steps=20, constraints=True, heteronuc_type=
'15N', atom1='N', atom2='H', spin_id=None)
```

#### Keyword Arguments

**dir:** The directory to place the files.

**force:** A flag which if set to True will cause the results file to be overwritten if it already exists.

**binary:** The name of the executable Modelfree program file.

**diff\_search:** See the Modelfree4 manual for 'diffusion\_search'.

**sims:** The number of Monte Carlo simulations.

**sim\_type:** See the Modelfree4 manual.

**trim:** See the Modelfree4 manual.

**steps:** See the Modelfree4 manual.

**constraints:** A flag specifying whether the parameters should be constrained. The default is to turn constraints on (constraints=True).

**heteronuc\_type:** A three letter string describing the heteronucleus type, ie 15N, 13C, etc.

**atom1:** The symbol of the X heteronucleus in the pdb file.

**atom2:** The symbol of the H nucleus in the pdb file.

**spin\_id:** The spin identification string.

#### Description

The following files are created

```
'dir/mfin',
'dir/mfdata',
'dir/mfpar',
'dir/mfmodel',
'dir/run.sh'.
```

The file 'dir/run.sh' contains the single command,

```
'modelfree4 -i mfin -d mfdata -p mfpar -m mfmodel
-o mfout -e out',
```

which can be used to execute modelfree4.

If you would like to use a different Modelfree executable file, change the keyword argument 'binary' to the appropriate file name. If the file is not located within the environment's path, include the full path in front of the binary file name.

---

### 10.2.86 palmer.execute()

#### Synopsis

Function for executing Modelfree4.

#### Defaults

```
palmer.execute(self, dir=None, force=False, binary=
'modelfree4')
```

#### Keyword Arguments

**dir:** The directory to place the files.

**force:** A flag which if set to True will cause the results file to be overwritten if it already exists.

**binary:** The name of the executable Modelfree program file.

#### Description

Modelfree 4 will be executed as

```
$ modelfree4 -i mfin -d mfdata -p mfpar -m
mfmodel -o mfout -e out
```

If a PDB file is loaded and non-isotropic diffusion is selected, then the file name will be placed on the command line as '-s **pdb\_file\_name**'.

If you would like to use a different Modelfree executable file, change the keyword argument 'binary' to the appropriate file name. If the file is not located within the environment's path, include the full path in front of the binary file name.

---

**10.2.87 palmer.extract()****Description****Synopsis**

Function for extracting data from the Modelfree4 ‘mfout’ star formatted file.

**Defaults**

`palmer.extract(self, dir=None)`

**Keyword Arguments**

`dir`: The directory where the file ‘mfout’ is found.

This function is required for specifying where the paramagnetic centre is located in the loaded structure file. If no structure number is given, then the average atom position will be calculated if multiple structures are loaded.

A different set of structures than those loaded into the current data pipe can also be used to determine the position, or its average. This can be achieved by loading the alternative structures into another data pipe, and then specifying that pipe through the pipe argument.

If the `ave_pos` flag is set to `True`, the average position from all models will be used as the position of the paramagnetic centre. If `False`, then the positions from all structures will be used. If multiple positions are used, then a fast paramagnetic centre motion will be assumed so that PCSs for a single tensor will be calculated for each position, and the PCS values linearly averaged.

---

**10.2.88 paramag.centre()****Examples****Synopsis**

Specify which atom is the paramagnetic centre.

**Defaults**

`paramag.centre(self, pos=None, atom_id=None, pipe=None, verbosity=1, fix=True, ave_pos=True, force=False)`

**Keyword Arguments**

`pos`: The atomic position.

`atom_id`: The atom ID string.

`pipe`: The data pipe containing the structures to extract the centre from.

`verbosity`: The amount of information to print out.

`fix`: A flag specifying if the paramagnetic centre should be fixed during optimisation.

`ave_pos`: A flag specifying if the position of the atom is to be averaged across all models.

`force`: A flag which if `True` will cause the current paramagnetic centre to be overwritten.

If the paramagnetic centre is the lanthanide Dysprosium which is labelled as  $\text{Dy}$  in a loaded PDB file, then type one of:

```
relax> paramag.centre('Dy')
relax> paramag.centre(atom_id='Dy')
```

If the carbon atom ‘C1’ of residue ‘4’ in the PDB file is to be used as the paramagnetic centre, then type:

```
relax> paramag.centre(':4@C1')
```

To state that the Dy3+ atomic position is [0.136, 12.543, 4.356], type one of:

```
relax> paramag.centre([0.136, 12.543, 4.356])
relax> paramag.centre(pos=[0.136, 12.543, 4.356])
```

To find an unknown paramagnetic centre, type:

```
relax> paramag.centre(fix=False)
```

---

**10.2.89 pcs.back\_calc()****Synopsis**

Back calculate the pseudo-contact shifts.

**Defaults**

`pcs.back_calc(self, align_id=None)`

## Keyword Arguments

**align\_id:** The alignment ID string.

---

### 10.2.90 pcs.calc\_q\_factors()

#### Synopsis

Calculate the PCS Q-factor for the selected spins.

#### Defaults

**pcs.calc\_q\_factors**(self, spin\_id=None)

## Keyword Arguments

**spin\_id:** The spin ID string for restricting to subset of all selected spins.

## Description

For this function to work, the back-calculated PCS data must first be generated by the analysis specific code. Otherwise a warning will be given.

## Examples

To calculate the PCS Q-factor for only the spins '@H26', '@H27', and '@H28', type one of:

```
relax> pcs.calc_q_factors('@H26 & @H27 & @H28')
```

```
relax> pcs.calc_q_factors(spin_id='@H26 & @H27 & @H28')
```

---

### 10.2.91 pcs.copy()

#### Synopsis

Copy PCS data from pipe\_from to pipe\_to.

#### Defaults

**pcs.copy**(self, pipe\_from=None, pipe\_to=None, align\_id=None)

## Keyword Arguments

**pipe\_from:** The name of the pipe to copy the PCS data from.

**pipe\_to:** The name of the pipe to copy the PCS data to.

**align\_id:** The alignment ID string.

## Description

This function will copy PCS data from 'pipe\_from' to 'pipe\_to'. If align\_id is not given then all PCS data will be copied, otherwise only a specific data set will be.

## Examples

To copy all PCS data from pipe 'm1' to pipe 'm9', type one of:

```
relax> pcs.copy('m1', 'm9')
```

```
relax> pcs.copy(pipe_from='m1', pipe_to='m9')
```

```
relax> pcs.copy('m1', 'm9', None)
```

```
relax> pcs.copy(pipe_from='m1', pipe_to='m9', align_id=None)
```

To copy only the 'Th' PCS data from 'm3' to 'm6', type one of:

```
relax> pcs.copy('m3', 'm6', 'Th')
```

```
relax> pcs.copy(pipe_from='m3', pipe_to='m6', align_id='Th')
```

---

### 10.2.92 pcs.corr\_plot()

#### Synopsis

Generate a correlation plot of the measured vs. the back-calculated PCSs.

#### Defaults

**pcs.corr\_plot**(self, format='grace', file='pcs\_corr\_plot.agr', dir=None, force=False)

## Keyword Arguments

**format:** The format of the plot data.

**file:** The name of the file.

**dir:** The directory name.

**force:** A flag which if True will cause the file to be overwritten.

## Description

Two formats are currently supported. If format is set to 'grace', then a Grace plot file will be created. If the format arg is set to None, then a plain text list of the measured and back-calculated data will be created.

## Examples

To create a Grace plot of the data, type:

```
relax> pcs.corr_plot()
```

To create a plain text list of the measured and back-calculated data, type one of:

```
relax> pcs.corr_plot(None)
```

```
relax> pcs.corr_plot(format=None)
```

---

### 10.2.93 pcs.delete()

#### Synopsis

Delete the PCS data corresponding to the alignment ID.

#### Defaults

```
pcs.delete(self, align_id=None)
```

#### Keyword Arguments

**align\_id**: The alignment ID string.

#### Examples

To delete the PCS data corresponding to align\_id='PH\_gel', type:

```
relax> pcs.delete('PH_gel')
```

---

### 10.2.94 pcs.display()

#### Synopsis

Display the PCS data corresponding to the alignment ID.

#### Defaults

```
pcs.display(self, align_id=None, bc=False)
```

## Keyword Arguments

**align\_id**: The alignment ID string.

**bc**: A flag which if set will display the back-calculated rather than measured RDCs.

## Examples

To display the 'phage' PCS data, type:

```
relax> pcs.display('phage')
```

---

### 10.2.95 pcs.read()

#### Synopsis

Read the PCS data from file.

#### Defaults

```
pcs.read(self, align_id=None, file=None, dir=None,
spin_id_col=None, mol_name_col=None, res_num_col=
None, res_name_col=None, spin_num_col=None,
spin_name_col=None, data_col=None, error_col=None,
sep=None, spin_id=None)
```

#### Keyword Arguments

**align\_id**: The alignment ID string.

**file**: The name of the file containing the PCS data.

**dir**: The directory where the file is located.

**spin\_id\_col**: The spin ID string column (an alternative to the mol, res, and spin name and number columns).

**mol\_name\_col**: The molecule name column (alternative to the spin\_id\_col).

**res\_num\_col**: The residue number column (alternative to the spin\_id\_col).

**res\_name\_col**: The residue name column (alternative to the spin\_id\_col).

**spin\_num\_col**: The spin number column (alternative to the spin\_id\_col).

**spin\_name\_col**: The spin name column (alternative to the spin\_id\_col).

**data\_col**: The PCS data column.

**error\_col**: The experimental error column.

**sep**: The column separator (the default is white space).

**spin\_id**: The spin ID string to restrict the loading of data to certain spin subsets.

## Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the `mol_name_col`, `res_num_col`, `res_name_col`, `spin_num_col`, and/or `spin_name_col` arguments can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The `spin_id` argument can be used to restrict the reading to certain spin types, for example only  $^{15}\text{N}$  spins when only residue information is in the file.

## Examples

The following commands will read the PCS data out of the file `Tb.txt` where the columns are separated by the symbol `,`, and store the PCSs under the ID `Tb`.

```
relax> pcs.read('Tb', 'Tb.txt', sep=',')
```

To read the  $^{15}\text{N}$  and  $^1\text{H}$  PCSs from the file `Eu.txt`, where the  $^{15}\text{N}$  values are in the 4<sup>th</sup> column and the  $^1\text{H}$  in the 9<sup>th</sup>, type both the following:

```
relax> pcs.read('Tb', 'Tb.txt', spin_id='@N', res_num_col=1, data_col=4)
```

```
relax> pcs.read('Tb', 'Tb.txt', spin_id='@H', res_num_col=1, data_col=9)
```

---

### 10.2.96 pcs.weight()

#### Synopsis

Set optimisation weights on the PCS data.

#### Defaults

```
pcs.weight(self, align_id=None, spin_id=None, weight=1.0)
```

#### Keyword Arguments

`align_id`: The alignment ID string.

`spin_id`: The spin ID string.

`weight`: The weighting value.

#### Description

This function can be used to force the PCS to contribute more or less to the chi-squared optimisation statistic. The higher the value, the more importance the PCS will have.

---

### 10.2.97 pcs.write()

#### Synopsis

Write the PCS data to file.

#### Defaults

```
pcs.write(self, align_id=None, file=None, dir=None, bc=False, force=False)
```

#### Keyword Arguments

`align_id`: The alignment ID string.

`file`: The name of the file.

`dir`: The directory name.

`bc`: A flag which if set will write out the back-calculated rather than measured RDCs.

`force`: A flag which if True will cause the file to be overwritten.

#### Description

If no directory name is given, the file will be placed in the current working directory. The `'align_id'` argument are required for selecting which PCS data set will be written to file.

---

### 10.2.98 pdc.read()

#### Synopsis

Read the Bruker Protein Dynamics Centre (PDC) file.

#### Defaults

```
pdc.read(self, ri_id=None, file=None, dir=None)
```

#### Keyword Arguments

`ri_id`: The relaxation data ID string.

`file`: The name of the PDC file.

`dir`: The directory where the file is located.

## Description

This user function is used to load all of the data out of a Bruker PDC file for subsequent analysis within relax.

## Defaults

**pipe.create**(self, pipe\_name=None, pipe\_type=None)

## Keyword Arguments

**pipe\_name**: The name of the data pipe.

**pipe\_type**: The type of data pipe.

### 10.2.99 pipe.copy()

## Synopsis

Copy a data pipe.

## Defaults

**pipe.copy**(self, pipe\_from=None, pipe\_to=None)

## Keyword Arguments

**pipe\_from**: The name of the source data pipe to copy the data from.

**pipe\_to**: The name of the target data pipe to copy the data to.

## Description

This allows the contents of a data pipe to be copied. If the source data pipe is not set, the current data pipe will be assumed. The target data pipe must not yet exist.

## Examples

To copy the contents of the 'm1' data pipe to the 'm2' data pipe, type:

```
relax> pipe.copy('m1', 'm2')
```

```
relax> pipe.copy(pipe_from='m1', pipe_to='m2')
```

If the current data pipe is 'm1', then the following command can be used:

```
relax> pipe.copy(pipe_to='m2')
```

## Description

The data pipe name can be any string however the data pipe type can only be one of the following:

'ct' – Consistency testing,

'frame order' – The Frame Order theories,

'jw' – Reduced spectral density mapping,

'hybrid' – A special hybrid pipe,

'mf' – Model-free analysis,

'N-state' – N-state model of domain motions,

'noe' – Steady state NOE calculation,

'relax\_fit' – Relaxation curve fitting,

## Examples

To set up a model-free analysis data pipe with the name 'm5', type:

```
relax> pipe.create('m5', 'mf')
```

### 10.2.101 pipe.current()

## Synopsis

Print the name of the current data pipe.

## Defaults

**pipe.current**(self)

## Examples

To run the user function, type:

```
relax> pipe.current()
```

### 10.2.100 pipe.create()

## Synopsis

Add a new data pipe to the relax data store.



### 10.2.102 pipe.delete()

#### Synopsis

Delete a data pipe from the relax data store.

#### Defaults

`pipe.delete(self, pipe_name=None)`

#### Keyword Arguments

`pipe_name`: The name of the data pipe to delete.

#### Description

This will permanently remove the data pipe and all of its contents from the relax data store. If the pipe name is not given, then all data pipes will be deleted.

#### Keyword Arguments

`hybrid`: The name of the hybrid data pipe to create.

`pipes`: An array containing the names of all data pipes to hybridise.

#### Description

This user function can be used to construct hybrid models. An example of the use of a hybrid model could be if the protein consists of two independent domains. These two domains could be analysed separately, each having their own optimised diffusion tensors. The N-terminal domain data pipe could be called 'N\_sphere' while the C-terminal domain could be called 'C\_ellipsoid'. These two data pipes could then be hybridised into a single data pipe. This hybrid data pipe can then be compared via model selection to a data pipe whereby the entire protein is assumed to have a single diffusion tensor.

The requirements for data pipes to be hybridised is that the molecules, sequences, and spin systems for all the data pipes is the same, and that no spin system is allowed to be selected in two or more data pipes. The selections must not overlap to allow for rigorous statistical comparisons.

---

### 10.2.103 pipe.display()

#### Synopsis

Print a list of all the data pipes.

#### Defaults

`pipe.display(self)`

#### Examples

To run the user function, type:

```
relax> pipe.display()
```

#### Examples

The two data pipes 'N\_sphere' and 'C\_ellipsoid' could be hybridised into a single data pipe called 'mixed model' by typing:

```
relax> pipe.hybridise('mixed model',
['N_sphere', 'C_ellipsoid'])
```

```
relax> pipe.hybridise(hybrid='mixed model',
pipes=['N_sphere', 'C_ellipsoid'])
```

---

### 10.2.105 pipe.switch()

#### Synopsis

Switch between the data pipes of the relax data store.

#### Defaults

`pipe.switch(self, pipe_name=None)`

#### Keyword Arguments

`pipe_name`: The name of the data pipe.

---

### 10.2.104 pipe.hybridise()

#### Synopsis

Create a hybrid data pipe by fusing a number of other data pipes.

#### Defaults

`pipe.hybridise(self, hybrid=None, pipes=None)`

## Description

This will switch between the various data pipes within the relax data store.

## Examples

To switch to the 'ellipsoid' data pipe, type:

```
relax> pipe.switch('ellipsoid')
relax> pipe.switch(pipe_name='ellipsoid')
```

---

### 10.2.106 pymol.cartoon()

## Synopsis

Apply the PyMOL cartoon style and colour by secondary structure.

## Defaults

**pymol.cartoon(self)**

## Description

This applies the PyMOL cartoon style which is equivalent to hiding everything and clicking on show cartoon. It also colours the cartoon with red helices, yellow strands, and green loops. The following commands are executed:

```
cmd.hide('everything', file)
cmd.show('cartoon', file)
util.cbss(file, 'red', 'yellow', 'green')
```

where file is the file name without the '.pdb' extension.

## Examples

To apply this user function, type:

```
relax> pymol.cartoon()
```

---

### 10.2.107 pymol.clear\_history()

## Synopsis

Clear the PyMOL command history.

## Defaults

**pymol.clear\_history(self)**

## Description

This will clear the Pymol history from memory.

---

### 10.2.108 pymol.command()

## Synopsis

Execute a user supplied PyMOL command.

## Defaults

**pymol.command(self, command=None)**

## Keyword Arguments

command: The PyMOL command to execute.

## Description

This allows PyMOL commands to be passed to the program. This can be useful for automation or scripting.

## Examples

To reinitialise the PyMOL instance, type:

```
relax> pymol.command("reinitialise")
```

---

### 10.2.109 pymol.cone\_pdb()

## Synopsis

Display the cone PDB geometric object.

## Defaults

**pymol.cone\_pdb(self, file=None)**

## Keyword Arguments

file: The name of the PDB file containing the cone geometric object.

## Description

The PDB file containing the geometric object must be created using the complementary `frame_order.cone_pdb` or `n_state_model.cone_pdb` user functions.

The cone PDB file is read in using the command:

```
load file
```

The average CoM-pivot point vector, the residue 'AVE' is displayed using the commands:

```
select resn AVE
show sticks, 'sele'
color blue, 'sele'
```

The cone object, the residue 'CON', is displayed using the commands:

```
select resn CON
hide ('sele')
show sticks, 'sele'
color white, 'sele'
```

---

### 10.2.110 pymol.macro\_apply()

## Synopsis

Execute PyMOL macros.

## Defaults

```
pymol.macro_apply(self, data_type=None, style='classic',
colour_start=None, colour_end=None, colour_list=None)
```

## Keyword Arguments

**data\_type:** The data type to map to the structure.

**style:** The style of the macro.

**colour\_start:** The starting colour, either an array or string, of the linear colour gradient.

**colour\_end:** The ending colour, either an array or string, of the linear colour gradient.

**colour\_list:** The list of colours to match the start and end strings.

## Description

This allows spin specific values to be mapped to a structure through PyMOL macros. Currently only the 'classic' style, which is described below, is available.

## Examples

To map the order parameter values,  $S^2$ , onto the structure using the classic style, type:

```
relax> pymol.macro_apply('S2')
relax> pymol.macro_apply(data_type='S2')
relax> pymol.macro_apply(data_type='S2',
style="classic")
```

## Colour

The values are coloured based on a linear colour gradient which is specified through the starting and ending colours. These can either be a string to identify one of the RGB (red, green, blue) colour arrays listed in the tables below, or you can give the RGB vector itself. For example, 'white' and [1.0, 1.0, 1.0] both select the same colour. Leaving both colours unset will select the default colour gradient which for each type of analysis is described below.

When supplying the colours as strings, two lists of colours can be selected from which to match the strings. These are the default Molmol colour list and the X11 colour list, both of which are described in the tables below. The default behaviour is to first search the Molmol list and then the X11 colour list, raising an error if neither contain the name. To explicitly select these lists, set the colour list to either 'molmol' or 'x11'.

## Model-free classic style

Creator: Edward d'Auvergne

Argument string: "classic"

Description: The classic style draws the backbone of a protein in a cylindrical bond style. Rather than colouring the amino acids to which the NH bond belongs, the three covalent bonds of the peptide bond from Ca to Ca in which the NH bond is located are coloured. Deselected residues are shown as black lines.

Supported data types:

(see table 10.25)

## Molmol RGB colour arrays

The following table is a list of colours used in Molmol and their corresponding RGB colour values ranging from 0 to 1.

(see table 10.26)

Table 10.25: First table for the `pymol.macro_apply()` user function.

| Data type                  | String      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
|----------------------------|-------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $S^2$ .                    | 'S2'        | The standard model-free order parameter, equal to $S_f^2$ . S2s for the two timescale models. The default colour gradient starts at 'yellow' and ends at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                           |
| $S_f^2$ .                  | 'S2f'       | The order parameter of the faster of two internal motions. Residues which are described by model-free models m1 to m4, the single timescale models, are illustrated as white neon bonds. The default colour gradient is the same as that for the $S^2$ data type.                                                                                                                                                                                                                                                                                                         |
| $S_s^2$ .                  | 'S2s'       | The order parameter of the slower of two internal motions. This functions exactly as $S_f^2$ except that $S_s^2$ is plotted instead.                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Amplitude of fast motions. | 'amp_fast'  | Model independent display of the amplit of fast motions. For residues described by model-free models m5 to m8, the value plotted is that of $S_f^2$ . However, for residues described by models m1 to m4, what is shown is dependent on the timescale of the motions. This is because these single timescale models can, at times, be perfect approximations to the more complex two timescale models. Hence if $\tau_e$ is less than 200 ps, $S^2$ is plotted. Otherwise the peptide bond is coloured white. The default colour gradient is the same as that for $S^2$ . |
| Amplitude of slow motions. | 'amp_slow'  | Model independent display of the amplit of slow motions, arbitrarily defined as motions slower than 200 ps. For residues described by model-free models m5 to m8, the order parameter $S^2$ is plotted if $\tau_s > 200$ ps. For models m1 to m4, $S^2$ is plotted if $\tau_e > 200$ ps. The default colour gradient is the same as that for $S^2$ .                                                                                                                                                                                                                      |
| $\tau_e$ .                 | 'te'        | The correlation time, $\tau_e$ . The default colour gradient starts at 'turquoise' and ends at 'blue'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| $\tau_f$ .                 | 'tf'        | The correlation time, $\tau_f$ . The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| $\tau_s$ .                 | 'ts'        | The correlation time, $\tau_s$ . The default colour gradient starts at 'blue' and ends at 'black'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Timescale of fast motions  | 'time_fast' | Model independent display of the timescale of fast motions. For models m5 to m8, only the parameter $\tau_f$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is less than 200 ps. All other residues are assumed to have a correlation of zero. The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                              |
| Timescale of slow motions  | 'time_slow' | Model independent display of the timescale of slow motions. For models m5 to m8, only the parameter $\tau_s$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is greater than 200 ps. All other residues are coloured white. The default colour gradient is the same as that of $\tau_s$ .                                                                                                                                                                                                                                                  |
| Chemical exchange          | 'Rex'       | The chemical exchange, $R_{ex}$ . Residues which experience no chemical exchange are coloured white. The default colour gradient starts at 'yellow' and finishes at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                |

Table 10.26: Second table for the `pymol.macro_apply()` user function.

| Name           | Red   | Green | Blue  |
|----------------|-------|-------|-------|
| 'black'        | 0.000 | 0.000 | 0.000 |
| 'navy'         | 0.000 | 0.000 | 0.502 |
| 'blue'         | 0.000 | 0.000 | 1.000 |
| 'dark green'   | 0.000 | 0.392 | 0.000 |
| 'green'        | 0.000 | 1.000 | 0.000 |
| 'cyan'         | 0.000 | 1.000 | 1.000 |
| 'turquoise'    | 0.251 | 0.878 | 0.816 |
| 'royal blue'   | 0.255 | 0.412 | 0.882 |
| 'aquamarine'   | 0.498 | 1.000 | 0.831 |
| 'sky green'    | 0.529 | 0.808 | 0.922 |
| 'dark violet'  | 0.580 | 0.000 | 0.827 |
| 'pale green'   | 0.596 | 0.984 | 0.596 |
| 'purple'       | 0.627 | 0.125 | 0.941 |
| 'brown'        | 0.647 | 0.165 | 0.165 |
| 'light blue'   | 0.678 | 0.847 | 0.902 |
| 'grey'         | 0.745 | 0.745 | 0.745 |
| 'light grey'   | 0.827 | 0.827 | 0.827 |
| 'violet'       | 0.933 | 0.510 | 0.933 |
| 'light coral'  | 0.941 | 0.502 | 0.502 |
| 'khaki'        | 0.941 | 0.902 | 0.549 |
| 'beige'        | 0.961 | 0.961 | 0.863 |
| 'red'          | 1.000 | 0.000 | 0.000 |
| 'magenta'      | 1.000 | 0.000 | 1.000 |
| 'deep pink'    | 1.000 | 0.078 | 0.576 |
| 'orange red'   | 1.000 | 0.271 | 0.000 |
| 'hot pink'     | 1.000 | 0.412 | 0.706 |
| 'coral'        | 1.000 | 0.498 | 0.314 |
| 'dark orange'  | 1.000 | 0.549 | 0.000 |
| 'orange'       | 1.000 | 0.647 | 0.000 |
| 'pink'         | 1.000 | 0.753 | 0.796 |
| 'gold'         | 1.000 | 0.843 | 0.000 |
| 'yellow'       | 1.000 | 1.000 | 0.000 |
| 'light yellow' | 1.000 | 1.000 | 0.878 |
| 'ivory'        | 1.000 | 1.000 | 0.941 |
| 'white'        | 1.000 | 1.000 | 1.000 |

## X11 RGB colour arrays

The following table is the list of X11 colour names and their corresponding RGB colour values ranging from 0 to 255.

(see table [10.27](#))

---

### 10.2.111 pymol.macro\_run()

#### Synopsis

Open and execute the PyMOL macro file.

#### Defaults

`pymol.macro_run(self, file=None, dir='pymol')`

#### Keyword Arguments

`file`: The name of the PyMOL macro file.

`dir`: The directory name.

#### Description

This user function is for opening and running a PyMOL macro located within a text file.

#### Examples

To execute the macro file 's2.pml' located in the directory 'pymol', type:

```
relax> pymol.macro_run(file='s2.pml')
```

```
relax> pymol.macro_run(file='s2.pml', dir='pymol')
```

---

### 10.2.112 pymol.macro\_write()

#### Synopsis

Create PyMOL macros.

#### Defaults

`pymol.macro_write(self, data_type=None, style='classic', colour_start=None, colour_end=None, colour_list=None, file=None, dir='pymol', force=False)`

## Keyword Arguments

`data_type`: The data type to map to the structure.

`style`: The style of the macro.

`colour_start`: The starting colour, either an array or string, of the linear colour gradient.

`colour_end`: The ending colour, either an array or string, of the linear colour gradient.

`colour_list`: The list of colours to match the start and end strings.

`file`: The optional name of the file.

`dir`: The optional directory to save the file to.

`force`: A flag which, if set to True, will cause the file to be overwritten.

#### Description

This allows residues specific values to be mapped to a structure through the creation of a PyMOL macro which can be executed in PyMOL by clicking on 'File, Macro, Execute User...'. Currently only the 'classic' style, which is described below, is available.

#### Examples

To create a PyMOL macro mapping the order parameter values,  $S^2$ , onto the structure using the classic style, type:

```
relax> pymol.macro_write('S2')
```

```
relax> pymol.macro_write(data_type='S2')
```

```
relax> pymol.macro_write(data_type='S2', style="classic", file='s2.pml', dir='pymol')
```

#### Colour

The values are coloured based on a linear colour gradient which is specified through the starting and ending colours. These can either be a string to identify one of the RGB (red, green, blue) colour arrays listed in the tables below, or you can give the RGB vector itself. For example, 'white' and [1.0, 1.0, 1.0] both select the same colour. Leaving both colours unset will select the default colour gradient which for each type of analysis is described below.

When supplying the colours as strings, two lists of colours can be selected from which to match the strings. These are the default Molmol colour list and the X11 colour list, both of which are described in the tables below. The default behaviour is to first search the Molmol list and then the X11 colour list, raising an error if neither contain the name. To explicitly select these lists, set the colour list to either 'molmol' or 'x11'.

Table 10.27: Third table for the `pymol.macro_apply()` user function.

| Name                | Red | Green | Blue |
|---------------------|-----|-------|------|
| snow                | 255 | 250   | 250  |
| ghost white         | 248 | 248   | 255  |
| white smoke         | 245 | 245   | 245  |
| gainsboro           | 220 | 220   | 220  |
| floral white        | 255 | 250   | 240  |
| old lace            | 253 | 245   | 230  |
| linen               | 250 | 240   | 230  |
| antique white       | 250 | 235   | 215  |
| papaya whip         | 255 | 239   | 213  |
| blanched almond     | 255 | 235   | 205  |
| bisque              | 255 | 228   | 196  |
| peach puff          | 255 | 218   | 185  |
| navajo white        | 255 | 222   | 173  |
| moccasin            | 255 | 228   | 181  |
| cornsilk            | 255 | 248   | 220  |
| ivory               | 255 | 255   | 240  |
| lemon chiffon       | 255 | 250   | 205  |
| seashell            | 255 | 245   | 238  |
| honeydew            | 240 | 255   | 240  |
| mint cream          | 245 | 255   | 250  |
| azure               | 240 | 255   | 255  |
| alice blue          | 240 | 248   | 255  |
| lavender            | 230 | 230   | 250  |
| lavender blush      | 255 | 240   | 245  |
| misty rose          | 255 | 228   | 225  |
| white               | 255 | 255   | 255  |
| black               | 0   | 0     | 0    |
| dark slate grey     | 47  | 79    | 79   |
| dim grey            | 105 | 105   | 105  |
| slate grey          | 112 | 128   | 144  |
| light slate grey    | 119 | 136   | 153  |
| grey                | 190 | 190   | 190  |
| light grey          | 211 | 211   | 211  |
| midnight blue       | 25  | 25    | 112  |
| navy                | 0   | 0     | 128  |
| cornflower blue     | 100 | 149   | 237  |
| dark slate blue     | 72  | 61    | 139  |
| slate blue          | 106 | 90    | 205  |
| medium slate blue   | 123 | 104   | 238  |
| light slate blue    | 132 | 112   | 255  |
| medium blue         | 0   | 0     | 205  |
| royal blue          | 65  | 105   | 225  |
| blue                | 0   | 0     | 255  |
| dodger blue         | 30  | 144   | 255  |
| deep sky blue       | 0   | 191   | 255  |
| sky blue            | 135 | 206   | 235  |
| light sky blue      | 135 | 206   | 250  |
| steel blue          | 70  | 130   | 180  |
| light steel blue    | 176 | 196   | 222  |
| light blue          | 173 | 216   | 230  |
| powder blue         | 176 | 224   | 230  |
| pale turquoise      | 175 | 238   | 238  |
| dark turquoise      | 0   | 206   | 209  |
| medium turquoise    | 72  | 209   | 204  |
| turquoise           | 64  | 224   | 208  |
| cyan                | 0   | 255   | 255  |
| light cyan          | 224 | 255   | 255  |
| cadet blue          | 95  | 158   | 160  |
| medium aquamarine   | 102 | 205   | 170  |
| aquamarine          | 127 | 255   | 212  |
| dark green          | 0   | 100   | 0    |
| dark olive green    | 85  | 107   | 47   |
| dark sea green      | 143 | 188   | 143  |
| sea green           | 46  | 139   | 87   |
| medium sea green    | 60  | 179   | 113  |
| light sea green     | 32  | 178   | 170  |
| pale green          | 152 | 251   | 152  |
| spring green        | 0   | 255   | 127  |
| lawn green          | 124 | 252   | 0    |
| green               | 0   | 255   | 0    |
| chartreuse          | 127 | 255   | 0    |
| medium spring green | 0   | 250   | 154  |
| green yellow        | 173 | 255   | 47   |
| lime green          | 50  | 205   | 50   |

## Model-free classic style

Creator: Edward d’Auvergne

Argument string: "classic"

Description: The classic style draws the backbone of a protein in a cylindrical bond style. Rather than colouring the amino acids to which the NH bond belongs, the three covalent bonds of the peptide bond from Ca to Ca in which the NH bond is located are coloured. Deselected residues are shown as black lines.

Supported data types:

(see table [10.28](#))

## Molmol RGB colour arrays

The following table is a list of colours used in Molmol and their corresponding RGB colour values ranging from 0 to 1.

(see table [10.29](#))



Table 10.28: First table for the `pymol.macro_write()` user function.

| Data type                  | String      | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $S^2$ .                    | 'S2'        | The standard model-free order parameter, equal to $S_f^2$ .S2s for the two timescale models. The default colour gradient starts at 'yellow' and ends at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                             |
| $S_f^2$ .                  | 'S2f'       | The order parameter of the faster of two internal motions. Residues which are described by model-free models m1 to m4, the single timescale models, are illustrated as white neon bonds. The default colour gradient is the same as that for the $S^2$ data type.                                                                                                                                                                                                                                                                                                          |
| $S_s^2$ .                  | 'S2s'       | The order parameter of the slower of two internal motions. This functions exactly as $S_f^2$ except that $S_s^2$ is plotted instead.                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Amplitude of fast motions. | 'amp_fast'  | Model independent display of the amplite of fast motions. For residues described by model-free models m5 to m8, the value plotted is that of $S_f^2$ . However, for residues described by models m1 to m4, what is shown is dependent on the timescale of the motions. This is because these single timescale models can, at times, be perfect approximations to the more complex two timescale models. Hence if $\tau_e$ is less than 200 ps, $S^2$ is plotted. Otherwise the peptide bond is coloured white. The default colour gradient is the same as that for $S^2$ . |
| Amplitude of slow motions. | 'amp_slow'  | Model independent display of the amplite of slow motions, arbitrarily defined as motions slower than 200 ps. For residues described by model-free models m5 to m8, the order parameter $S^2$ is plotted if $\tau_s > 200$ ps. For models m1 to m4, $S^2$ is plotted if $\tau_e > 200$ ps. The default colour gradient is the same as that for $S^2$ .                                                                                                                                                                                                                      |
| $\tau_e$ .                 | 'te'        | The correlation time, $\tau_e$ . The default colour gradient starts at 'turquoise' and ends at 'blue'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| $\tau_f$ .                 | 'tf'        | The correlation time, $\tau_f$ . The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| $\tau_s$ .                 | 'ts'        | The correlation time, $\tau_s$ . The default colour gradient starts at 'blue' and ends at 'black'.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| Timescale of fast motions  | 'time_fast' | Model independent display of the timescale of fast motions. For models m5 to m8, only the parameter $\tau_f$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is less than 200 ps. All other residues are assumed to have a correlation time of zero. The default colour gradient is the same as that of $\tau_e$ .                                                                                                                                                                                                                          |
| Timescale of slow motions  | 'time_slow' | Model independent display of the timescale of slow motions. For models m5 to m8, only the parameter $\tau_s$ is plotted. For models m2 and m4, the parameter $\tau_e$ is plotted only if it is greater than 200 ps. All other residues are coloured white. The default colour gradient is the same as that of $\tau_s$ .                                                                                                                                                                                                                                                   |
| Chemical exchange          | 'Rex'       | The chemical exchange, $R_{ex}$ . Residues which experience no chemical exchange are coloured white. The default colour gradient starts at 'yellow' and finishes at 'red'.                                                                                                                                                                                                                                                                                                                                                                                                 |

Table 10.29: Second table for the `pymol.macro_write()` user function.

| Name           | Red   | Green | Blue  |
|----------------|-------|-------|-------|
| 'black'        | 0.000 | 0.000 | 0.000 |
| 'navy'         | 0.000 | 0.000 | 0.502 |
| 'blue'         | 0.000 | 0.000 | 1.000 |
| 'dark green'   | 0.000 | 0.392 | 0.000 |
| 'green'        | 0.000 | 1.000 | 0.000 |
| 'cyan'         | 0.000 | 1.000 | 1.000 |
| 'turquoise'    | 0.251 | 0.878 | 0.816 |
| 'royal blue'   | 0.255 | 0.412 | 0.882 |
| 'aquamarine'   | 0.498 | 1.000 | 0.831 |
| 'sky green'    | 0.529 | 0.808 | 0.922 |
| 'dark violet'  | 0.580 | 0.000 | 0.827 |
| 'pale green'   | 0.596 | 0.984 | 0.596 |
| 'purple'       | 0.627 | 0.125 | 0.941 |
| 'brown'        | 0.647 | 0.165 | 0.165 |
| 'light blue'   | 0.678 | 0.847 | 0.902 |
| 'grey'         | 0.745 | 0.745 | 0.745 |
| 'light grey'   | 0.827 | 0.827 | 0.827 |
| 'violet'       | 0.933 | 0.510 | 0.933 |
| 'light coral'  | 0.941 | 0.502 | 0.502 |
| 'khaki'        | 0.941 | 0.902 | 0.549 |
| 'beige'        | 0.961 | 0.961 | 0.863 |
| 'red'          | 1.000 | 0.000 | 0.000 |
| 'magenta'      | 1.000 | 0.000 | 1.000 |
| 'deep pink'    | 1.000 | 0.078 | 0.576 |
| 'orange red'   | 1.000 | 0.271 | 0.000 |
| 'hot pink'     | 1.000 | 0.412 | 0.706 |
| 'coral'        | 1.000 | 0.498 | 0.314 |
| 'dark orange'  | 1.000 | 0.549 | 0.000 |
| 'orange'       | 1.000 | 0.647 | 0.000 |
| 'pink'         | 1.000 | 0.753 | 0.796 |
| 'gold'         | 1.000 | 0.843 | 0.000 |
| 'yellow'       | 1.000 | 1.000 | 0.000 |
| 'light yellow' | 1.000 | 1.000 | 0.878 |
| 'ivory'        | 1.000 | 1.000 | 0.941 |
| 'white'        | 1.000 | 1.000 | 1.000 |

## X11 RGB colour arrays

The following table is the list of X11 colour names and their corresponding RGB colour values ranging from 0 to 255.

(see table [10.30](#))

```
select resn AXS
hide ('sele')
show sticks, 'sele'
color cyan, 'sele'
label 'sele', name
```

---

### 10.2.113 pymol.tensor\_pdb()

#### Synopsis

Display the diffusion tensor PDB geometric object over the loaded PDB.

#### Defaults

**pymol.tensor\_pdb**(self, file=None)

#### Keyword Arguments

**file**: The name of the PDB file containing the tensor geometric object.

#### Description

In executing this user function, a PDB file must have previously been loaded into this data pipe a geometric object or polygon representing the Brownian rotational diffusion tensor will be overlain with the loaded PDB file and displayed within PyMOL. The PDB file containing the geometric object must be created using the complementary `structure.create_diff_tensor_pdb` user function.

The tensor PDB file is read in using the command:

```
load file
```

The centre of mass residue 'COM' is displayed using the commands:

```
select resn COM
show dots, 'sele'
color blue, 'sele'
```

The axes of the diffusion tensor, the residue 'AXS', is displayed using the commands:

The simulation axes, the residues 'SIM', are displayed using the commands:

```
select resn SIM
colour cyan, 'sele'
```

---

### 10.2.114 pymol.vector\_dist()

#### Synopsis

Display the PDB file representation of the XH vector distribution.

#### Defaults

**pymol.vector\_dist**(self, file='XH\_dist.pdb')

#### Keyword Arguments

**file**: The name of the PDB file containing the vector distribution.

#### Description

A PDB file of the macromolecule must have previously been loaded as the vector distribution will be overlain with the macromolecule within PyMOL. The PDB file containing the vector distribution must be created using the complementary `structure.create_vector_dist` user function.

The vector distribution PDB file is read in using the command:

```
load file
```

---

Table 10.30: Third table for the `pymol.macro_write()` user function.

| Name                | Red | Green | Blue |
|---------------------|-----|-------|------|
| snow                | 255 | 250   | 250  |
| ghost white         | 248 | 248   | 255  |
| white smoke         | 245 | 245   | 245  |
| gainsboro           | 220 | 220   | 220  |
| floral white        | 255 | 250   | 240  |
| old lace            | 253 | 245   | 230  |
| linen               | 250 | 240   | 230  |
| antique white       | 250 | 235   | 215  |
| papaya whip         | 255 | 239   | 213  |
| blanched almond     | 255 | 235   | 205  |
| bisque              | 255 | 228   | 196  |
| peach puff          | 255 | 218   | 185  |
| navajo white        | 255 | 222   | 173  |
| moccasin            | 255 | 228   | 181  |
| cornsilk            | 255 | 248   | 220  |
| ivory               | 255 | 255   | 240  |
| lemon chiffon       | 255 | 250   | 205  |
| seashell            | 255 | 245   | 238  |
| honeydew            | 240 | 255   | 240  |
| mint cream          | 245 | 255   | 250  |
| azure               | 240 | 255   | 255  |
| alice blue          | 240 | 248   | 255  |
| lavender            | 230 | 230   | 250  |
| lavender blush      | 255 | 240   | 245  |
| misty rose          | 255 | 228   | 225  |
| white               | 255 | 255   | 255  |
| black               | 0   | 0     | 0    |
| dark slate grey     | 47  | 79    | 79   |
| dim grey            | 105 | 105   | 105  |
| slate grey          | 112 | 128   | 144  |
| light slate grey    | 119 | 136   | 153  |
| grey                | 190 | 190   | 190  |
| light grey          | 211 | 211   | 211  |
| midnight blue       | 25  | 25    | 112  |
| navy                | 0   | 0     | 128  |
| cornflower blue     | 100 | 149   | 237  |
| dark slate blue     | 72  | 61    | 139  |
| slate blue          | 106 | 90    | 205  |
| medium slate blue   | 123 | 104   | 238  |
| light slate blue    | 132 | 112   | 255  |
| medium blue         | 0   | 0     | 205  |
| royal blue          | 65  | 105   | 225  |
| blue                | 0   | 0     | 255  |
| dodger blue         | 30  | 144   | 255  |
| deep sky blue       | 0   | 191   | 255  |
| sky blue            | 135 | 206   | 235  |
| light sky blue      | 135 | 206   | 250  |
| steel blue          | 70  | 130   | 180  |
| light steel blue    | 176 | 196   | 222  |
| light blue          | 173 | 216   | 230  |
| powder blue         | 176 | 224   | 230  |
| pale turquoise      | 175 | 238   | 238  |
| dark turquoise      | 0   | 206   | 209  |
| medium turquoise    | 72  | 209   | 204  |
| turquoise           | 64  | 224   | 208  |
| cyan                | 0   | 255   | 255  |
| light cyan          | 224 | 255   | 255  |
| cadet blue          | 95  | 158   | 160  |
| medium aquamarine   | 102 | 205   | 170  |
| aquamarine          | 127 | 255   | 212  |
| dark green          | 0   | 100   | 0    |
| dark olive green    | 85  | 107   | 47   |
| dark sea green      | 143 | 188   | 143  |
| sea green           | 46  | 139   | 87   |
| medium sea green    | 60  | 179   | 113  |
| light sea green     | 32  | 178   | 170  |
| pale green          | 152 | 251   | 152  |
| spring green        | 0   | 255   | 127  |
| lawn green          | 124 | 252   | 0    |
| green               | 0   | 255   | 0    |
| chartreuse          | 127 | 255   | 0    |
| medium spring green | 0   | 250   | 154  |
| green yellow        | 173 | 255   | 47   |
| lime green          | 50  | 205   | 50   |

**10.2.115 pymol.view()****Synopsis**

View the collection of molecules from the loaded PDB file.

**Defaults**

**pymol.view**(self)

**Description**

This will simply launch Pymol.

**Examples**

```
relax> pymol.view()
```

**Keyword Arguments**

**spin\_id**: The spin ID string for restricting to subset of all selected spins.

**Description**

For this function to work, the back-calculated RDC data must first be generated by the analysis specific code. Otherwise a warning will be given.

**Examples**

To calculate the RDC Q-factor for only the spins '@H26', '@H27', and '@H28', type one of:

```
relax> rdc.calc_q_factors('@H26 & @H27 & @H28')
```

```
relax> rdc.calc_q_factors(spin_id='@H26 & @H27 & @H28')
```

**10.2.116 rdc.back\_calc()****Synopsis**

Back calculate RDCs.

**Defaults**

**rdc.back\_calc**(self, align\_id=None)

**Keyword Arguments**

**align\_id**: The alignment ID string.

**10.2.118 rdc.copy()****Synopsis**

Copy RDC data from pipe\_from to pipe\_to.

**Defaults**

**rdc.copy**(self, pipe\_from=None, pipe\_to=None, align\_id=None)

**Keyword Arguments**

**pipe\_from**: The name of the pipe to copy the RDC data from.

**pipe\_to**: The name of the pipe to copy the RDC data to.

**align\_id**: The alignment ID string.

**10.2.117 rdc.calc\_q\_factors()****Synopsis**

Calculate the RDC Q-factor for the selected spins.

**Defaults**

**rdc.calc\_q\_factors**(self, spin\_id=None)

**Description**

This function will copy RDC data from 'pipe\_from' to 'pipe\_to'. If align\_id is not given then all RDC data will be copied, otherwise only a specific data set will be.

## Examples

To copy all RDC data from pipe ‘m1’ to pipe ‘m9’, type one of:

```
relax> rdc.copy('m1', 'm9')
relax> rdc.copy(pipe_from='m1', pipe_to='m9')
relax> rdc.copy('m1', 'm9', None)
relax> rdc.copy(pipe_from='m1', pipe_to='m9', align_id=None)
```

To copy only the ‘Th’ RDC data from ‘m3’ to ‘m6’, type one of:

```
relax> rdc.copy('m3', 'm6', 'Th')
relax> rdc.copy(pipe_from='m3', pipe_to='m6', align_id='Th')
```

---

### 10.2.119 rdc.corr\_plot()

#### Synopsis

Generate a correlation plot of the measured vs. the back-calculated RDCs.

#### Defaults

```
rdc.corr_plot(self, format='grace', file='rdc_corr_plot.agr',
dir=None, force=False)
```

#### Keyword Arguments

**format:** The format of the plot data.

**file:** The name of the file.

**dir:** The directory name.

**force:** A flag which if True will cause the file to be overwritten.

#### Description

Two formats are currently supported. If format is set to ‘grace’, then a Grace plot file will be created. If the format arg is set to None, then a plain text list of the measured and back-calculated data will be created.

## Examples

To create a Grace plot of the data, type:

```
relax> rdc.corr_plot()
```

To create a plain text list of the measured and back-calculated data, type one of:

```
relax> rdc.corr_plot(None)
relax> rdc.corr_plot(format=None)
```

---

### 10.2.120 rdc.delete()

#### Synopsis

Delete the RDC data corresponding to the alignment ID.

#### Defaults

```
rdc.delete(self, align_id=None)
```

#### Keyword Arguments

**align\_id:** The alignment ID string.

#### Examples

To delete the RDC data corresponding to align\_id=‘PH\_gel’, type:

```
relax> rdc.delete('PH_gel')
```

---

### 10.2.121 rdc.display()

#### Synopsis

Display the RDC data corresponding to the alignment ID.

#### Defaults

```
rdc.display(self, align_id=None, bc=False)
```

#### Keyword Arguments

**align\_id:** The alignment ID string.

**bc:** A flag which if set will display the back-calculated rather than measured RDCs.

## Examples

To display the ‘phage’ RDC data, type:

```
relax> rdc.display('phage')
```

---

### 10.2.122 rdc.read()

## Synopsis

Read the RDC data from file.

## Defaults

```
rdc.read(self, align_id=None, file=None, dir=None,
data_type='D', spin_id_col=None, mol_name_col=None,
res_num_col=None, res_name_col=None, spin_num_col=
None, spin_name_col=None, data_col=None, error_col=
None, sep=None, spin_id=None, neg_g_corr=False)
```

## Keyword Arguments

**align\_id**: The alignment ID string.

**file**: The name of the file containing the RDC data.

**dir**: The directory where the file is located.

**data\_type**: Whether the RDC data is in the D or 2D format.

**spin\_id\_col**: The spin ID string column (an alternative to the mol, res, and spin name and number columns).

**mol\_name\_col**: The molecule name column (alternative to the spin\_id\_col).

**res\_num\_col**: The residue number column (alternative to the spin\_id\_col).

**res\_name\_col**: The residue name column (alternative to the spin\_id\_col).

**spin\_num\_col**: The spin number column (alternative to the spin\_id\_col).

**spin\_name\_col**: The spin name column (alternative to the spin\_id\_col).

**data\_col**: The RDC data column.

**error\_col**: The experimental error column.

**sep**: The column separator (the default is white space).

**spin\_id**: The spin ID string to restrict the loading of data to certain spin subsets.

**neg\_g\_corr**: A flag which is used to correct for the negative gyromagnetic ratio of <sup>15</sup>N.

## Description

The `data_type` argument is used to specify how the RDC is defined. It is a string which can be set to two values:

- ‘D’ means that the splitting in the aligned sample was taken as  $J + D$ .

- ‘2D’ means that the splitting in the aligned sample was assumed to be  $J + 2D$ .

Internally, relax uses the D notation. Therefore if set to ‘2D’, the values will be doubled when read in.

If `neg_g_corr` is set to True, a sign inversion will be applied to all RDC values to be loaded. This is sometimes needed for <sup>15</sup>N if the data is not compensated for the negative gyromagnetic ratio.

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the `mol_name_col`, `res_num_col`, `res_name_col`, `spin_num_col`, and/or `spin_name_col` arguments can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The `spin_id` argument can be used to restrict the reading to certain spin types, for example only <sup>15</sup>N spins when only residue information is in the file.

## Examples

The following commands will read the RDC data out of the file ‘Tb.txt’ where the columns are separated by the symbol ‘,’ and store the RDCs under the ID ‘Tb’:

```
relax> rdc.read('Tb', 'Tb.txt', sep=',')
```

If the individual spin RDC errors are located in the file ‘rdc\_err.txt’ in column number 5, then to read these values into relax, assuming  $J + D$  was measured, type one of:

```
relax> rdc.read('phage', 'rdc_err.txt',
data_type='D', error_col=5)
```

```
relax> rdc.read(align_id='phage', file=
'rdc_err.txt', data_type='D', error_col=
5)
```

If the RDCs correspond to the ‘N’ spin and other spin types such as <sup>1</sup>H, <sup>13</sup>C, etc. are loaded into relax, then type:

```
relax> rdc.read('Tb', 'Tb.txt', spin_id=
'@N')
```

---

### 10.2.123 rdc.weight()

## Synopsis

Set optimisation weights on the RDC data.

## Defaults

**rdc.weight**(self, align\_id=None, spin\_id=None, weight=1.0)

## Keyword Arguments

**align\_id**: The alignment ID string.

**spin\_id**: The spin ID string.

**weight**: The weighting value.

## Description

This function can be used to force the RDC to contribute more or less to the chi-squared optimisation statistic. The higher the value, the more importance the RDC will have.

---

### 10.2.124 rdc.write()

## Synopsis

Write the RDC data to file.

## Defaults

**rdc.write**(self, align\_id=None, file=None, dir=None, bc=False, force=False)

## Keyword Arguments

**align\_id**: The alignment ID string.

**file**: The name of the file.

**dir**: The directory name.

**bc**: A flag which if set will write out the back-calculated rather than measured RDCs.

**force**: A flag which if True will cause the file to be overwritten.

## Description

If no directory name is given, the file will be placed in the current working directory. The '**align\_id**' argument are required for selecting which RDC data set will be written to file.

---

### 10.2.125 relax\_data.back\_calc()

## Synopsis

Back calculate the relaxation data at the given frequency.

## Defaults

**relax\_data.back\_calc**(self, ri\_id=None, ri\_type=None, frq=None)

## Keyword Arguments

**ri\_id**: The relaxation data ID string.

**ri\_type**: The relaxation data type, ie 'R1', 'R2', or 'NOE'.

**frq**: The spectrometer frequency in Hz.

## Description

This allows relaxation data of the given type and frequency to be back calculated from the model parameter values.

---

### 10.2.126 relax\_data.copy()

## Synopsis

Copy relaxation data from one pipe to another.

## Defaults

**relax\_data.copy**(self, pipe\_from=None, pipe\_to=None, ri\_id=None)

## Keyword Arguments

**pipe\_from**: The name of the pipe to copy the relaxation data from.

**pipe\_to**: The name of the pipe to copy the relaxation data to.

**ri\_id**: The relaxation data ID string.

## Description

This will copy relaxation data from one data pipe to another. If the relaxation ID data string is not given then all relaxation data will be copied, otherwise only a specific data set will be copied.



## Examples

To copy all relaxation data from pipe 'm1' to pipe 'm9', type one of:

```
relax> relax_data.copy('m1', 'm9')
relax> relax_data.copy(pipe_from='m1',
pipe_to='m9')
relax> relax_data.copy('m1', 'm9', None)
relax> relax_data.copy(pipe_from='m1',
pipe_to='m9', ri_id=None)
```

To copy only the NOE relaxation data with the ID string of 'NOE\_800' from 'm3' to 'm6', type one of:

```
relax> relax_data.copy('m3', 'm6',
'NOE_800')
relax> relax_data.copy(pipe_from='m3',
pipe_to='m6', ri_id='NOE_800')
```

---

### 10.2.127 relax\_data.delete()

#### Synopsis

Delete the data corresponding to the relaxation data ID string.

#### Defaults

```
relax_data.delete(self, ri_id=None)
```

#### Keyword Arguments

*ri\_id*: The relaxation data ID string.

#### Description

The relaxation data corresponding to the given relaxation data ID string will be removed from the current data pipe.

#### Examples

To delete the relaxation data corresponding to the ID 'NOE\_600', type:

```
relax> relax_data.delete('NOE_600')
```

---

### 10.2.128 relax\_data.display()

#### Synopsis

Display the data corresponding to the relaxation data ID string.

#### Defaults

```
relax_data.display(self, ri_id=None)
```

#### Keyword Arguments

*ri\_id*: The relaxation data ID string.

#### Examples

To display the NOE relaxation data at 600 MHz with the ID string 'NOE\_600', type:

```
relax> relax_data.display('NOE_600')
```

---

### 10.2.129 relax\_data.peak\_intensity\_type()

#### Synopsis

Specify the type of peak intensity measurement used - i.e. height or volume.

#### Defaults

```
relax_data.peak_intensity_type(self, ri_id=None, type=None)
```

#### Keyword Arguments

*ri\_id*: The relaxation data ID string.

*type*: The peak intensity type.

#### Description

This is essential for BMRB data deposition. It is used to specify whether peak heights or peak volumes were measured. The two currently allowed values for the type argument are 'height' and 'volume'.

---

### 10.2.130 `relax_data.read()`

#### Synopsis

Read  $R_1$ ,  $R_2$ , or NOE relaxation data from a file.

#### Defaults

```
relax_data.read(self, ri_id=None, ri_type=None, frq=
None, file=None, dir=None, spin_id_col=None,
mol_name_col=None, res_num_col=None, res_name_col=
None, spin_num_col=None, spin_name_col=None,
data_col=None, error_col=None, sep=None, spin_id=
None)
```

#### Keyword Arguments

`ri_id`: The relaxation data ID string. This must be a unique identifier.

`ri_type`: The relaxation data type, i.e. 'R1', 'R2', or 'NOE'.

`frq`: The exact proton frequency of the spectrometer in Hertz. See the 'sfrq' parameter in the Varian propar file or the 'SF01' parameter in the Bruker acquis file.

`file`: The name of the file containing the relaxation data.

`dir`: The directory where the file is located.

`spin_id_col`: The spin ID string column (an alternative to the mol, res, and spin name and number columns).

`mol_name_col`: The molecule name column (alternative to the `spin_id_col`).

`res_num_col`: The residue number column (alternative to the `spin_id_col`).

`res_name_col`: The residue name column (alternative to the `spin_id_col`).

`spin_num_col`: The spin number column (alternative to the `spin_id_col`).

`spin_name_col`: The spin name column (alternative to the `spin_id_col`).

`data_col`: The relaxation data column.

`error_col`: The experimental error column.

`sep`: The column separator (the default is white space).

`spin_id`: The spin ID string to restrict the loading of data to certain spin subsets.

#### Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name

and number, and the spin name and number. Alternatively the molecule name, residue number, residue name, spin number and/or spin name columns can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The spin ID string can be used to restrict the reading to certain spin types, for example only  $^{15}\text{N}$  spins when only residue information is in the file.

#### Examples

The following commands will read the protein NOE relaxation data collected at 600 MHz out of a file called 'noe.600.out' where the residue numbers, residue names, data, errors are in the first, second, third, and forth columns respectively.

```
relax> relax_data.read('NOE.600', 'NOE',
599.7 * 1e6, 'noe.600.out', res_num_col=1,
res_name_col=2, data_col=3, error_col=4)
```

```
relax> relax_data.read(ri_id='NOE.600',
ri_type='NOE', frq=600.0 * 1e6, file=
'noe.600.out', res_num_col=1, res_name_col=2,
data_col=3, error_col=4)
```

The following commands will read the  $R_2$  data out of the file 'r2.out' where the residue numbers, residue names, data, errors are in the second, third, fifth, and sixth columns respectively. The columns are separated by commas.

```
relax> relax_data.read('R2.800', 'R2', 8.0 *
1e8, 'r2.out', res_num_col=2, res_name_col=3,
data_col=5, error_col=6, sep=',')
```

```
relax> relax_data.read(ri_id='R2.800',
ri_type='R2', frq=8.0*1e8, file='r2.out',
res_num_col=2, res_name_col=3, data_col=5,
error_col=6, sep=',')
```

The following commands will read the  $R_1$  data out of the file 'r1.out' where the columns are separated by the symbol '%'

```
relax> relax_data.read('R1.300', 'R1', 300.1
* 1e6, 'r1.out', sep='%')
```

---

### 10.2.131 `relax_data.temp-_calibration()`

#### Synopsis

Specify the temperature calibration method used.

#### Defaults

```
relax_data.temp_calibration(self, ri_id=None, method=
None)
```

## Keyword Arguments

`ri_id`: The relaxation data ID string.

`method`: The calibration method.

`'no temperature control applied'.`

## Description

This is essential for BMRB data deposition. The currently allowed methods are:

```
'methanol',
'monoethylene glycol',
'no calibration applied'.
```

Other strings will be accepted if supplied.

---

### 10.2.132 `relax_data.temp_control()`

## Synopsis

Specify the temperature control method used.

## Defaults

`relax_data.temp_control(self, ri_id=None, method=None)`

## Keyword Arguments

`ri_id`: The relaxation data ID string.

`method`: The control method.

## Description

This is essential for BMRB data deposition. The currently allowed methods are:

```
'single scan interleaving',
'temperature compensation block',
'single scan interleaving and temperature
compensation block',
'single fid interleaving',
'single experiment interleaving',
```

---

### 10.2.133 `relax_data.write()`

## Synopsis

Write relaxation data to a file.

## Defaults

`relax_data.write(self, ri_id=None, file=None, dir=None, bc=False, force=False)`

## Keyword Arguments

`ri_id`: The relaxation data ID string.

`file`: The name of the file.

`dir`: The directory name.

`force`: A flag which if True will cause the file to be overwritten.

## Description

If no directory name is given, the file will be placed in the current working directory. The relaxation data ID string is required for selecting which relaxation data to write to file.

---

### 10.2.134 `relax_fit.relax_time()`

## Synopsis

Set the relaxation delay time associated with each spectrum.

## Defaults

`relax_fit.relax_time(self, time=0.0, spectrum_id=None)`

## Keyword Arguments

`time`: The time, in seconds, of the relaxation period.

`spectrum_id`: The spectrum identification string.

## Description

Peak intensities should be loaded before calling this user function via the `spectrum.read_intensities` user function. The intensity values will then be associated with a spectrum identifier. To associate each spectrum identifier with a time point in the relaxation curve prior to optimisation, this user function should be called.

---

### 10.2.135 `relax_fit.select_model()`

#### Synopsis

Select the relaxation curve type.

#### Defaults

`relax_fit.select_model(self, model='exp')`

#### Keyword Arguments

`model`: The type of relaxation curve to fit.

#### Description

The supported relaxation experiments include the default two parameter exponential fit, selected by setting the `'fit_type'` argument to `'exp'`, and the three parameter inversion recovery experiment in which the peak intensity limit is a non-zero value, selected by setting the argument to `'inv'`.

The parameters of these two models are

`'exp'` – [Rx, I0],

`'inv'` – [Rx, I0, Iinf].

---

### 10.2.136 `reset()`

#### Synopsis

Reset relax.

## Defaults

`reset(self)`

All of the data of the relax data storage object will be erased and hence relax will return to its initial state.

---

### 10.2.137 `residue.copy()`

#### Synopsis

Copy all data associated with a residue.

#### Defaults

`residue.copy(self, pipe_from=None, res_from=None, pipe_to=None, res_to=None)`

#### Keyword Arguments

`pipe_from`: The data pipe containing the residue from which the data will be copied. This defaults to the current data pipe.

`res_from`: The residue ID string of the residue to copy the data from.

`pipe_to`: The data pipe to copy the data to. This defaults to the current data pipe.

`res_to`: The residue ID string of the residue to copy the data to.

#### Description

This will copy all the data associated with the identified residue to the new, non-existent residue. The new residue cannot currently exist.

#### Examples

To copy the residue data from residue 1 to the new residue 2, type:

```
relax> residue.copy(res_from=':1', res_to=':2')
```

To copy residue 1 of the molecule 'Old mol' to residue 5 of the molecule 'New mol', type:

```
relax> residue.copy(res_from='#Old mol:1', res_to='#New mol:5')
```

To copy the residue data of residue 1 from the data pipe 'm1' to 'm2', assuming the current data pipe is 'm1', type:

```
relax> residue.copy(res_from=':1', pipe_to='m2')
```

```
relax> residue.copy(pipe_from='m1',
res_from=':1', pipe_to='m2', res_to=':1')
```

---

### 10.2.138 residue.create()

#### Synopsis

Create a new residue.

#### Defaults

```
residue.create(self, res_num=None, res_name=None,
mol_name=None)
```

#### Keyword Arguments

**res\_num**: The residue number.

**res\_name**: The name of the residue.

**mol\_name**: The name of the molecule to add the residue to.

#### Description

Using this, a new sequence can be generated without using the sequence user functions. However if the sequence already exists, the new residue will be added to the end of the residue list (the residue numbers of this list need not be sequential). The same residue number cannot be used more than once. A corresponding single spin system will be created for this residue. The spin system number and name or additional spin systems can be added later if desired.

#### Examples

The following sequence of commands will generate the sequence 1 ALA, 2 GLY, 3 LYS:

```
relax> residue.create(1, 'ALA')
```

```
relax> residue.create(2, 'GLY')
```

```
relax> residue.create(3, 'LYS')
```

---

### 10.2.139 residue.delete()

#### Synopsis

Delete residues from the current data pipe.

#### Defaults

```
residue.delete(self, res_id=None)
```

#### Keyword Arguments

**res\_id**: The residue ID string.

#### Description

This can be used to delete a single or sets of residues. See the ID string documentation for more information. If spin system/atom ids are included a RelaxError will be raised.

#### Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '**<mol\_name>**', the name of the molecule, '**<res\_id>**', the residue identifier which can be a number, name, or range of numbers, '**<atom\_id>**', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.140 residue.display()

#### Synopsis

Display information about the residue(s).

#### Defaults

```
residue.display(self, res_id=None)
```

## Keyword Arguments

**res\_id:** The residue ID string.

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '`#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]`', where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.141 residue.name()

#### Synopsis

Name the residues.

#### Defaults

**residue.name**(self, res\_id=None, name=None, force=False)

#### Keyword Arguments

**res\_id:** The residue ID string corresponding to one or more residues.

**name:** The new name.

**force:** A flag which if True will cause the residue to be renamed.

#### Description

This simply allows residues to be named (or renamed).

## Examples

The following sequence of commands will rename the sequence {1 ALA, 2 GLY, 3 LYS} to {1 XXX, 2 XXX, 3 XXX}:

```
relax> residue.name(':', 'XXX', force=True)
relax> residue.name(':', 'XXX', force=True)
relax> residue.name(':', 'XXX', force=True)
```

Alternatively:

```
relax> residue.name(':1,2,3', 'XXX', force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '`#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]`', where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.142 residue.number()

#### Synopsis

Number the residues.

#### Defaults

**residue.number**(self, res\_id=None, number=None, force=False)

## Keyword Arguments

**res\_id:** The residue ID string corresponding to a single residue.

**number:** The new residue number.

**force:** A flag which if True will cause the residue to be renumbered.

## Description

This simply allows residues to be numbered. The new number cannot correspond to an existing residue.

## Examples

The following sequence of commands will renumber the sequence {1 ALA, 2 GLY, 3 LYS} to {101 ALA, 102 GLY, 103 LYS}:

```
relax> residue.number(':1', 101, force=True)
relax> residue.number(':2', 102, force=True)
relax> residue.number(':3', 103, force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

## Defaults

**results.display(self)**

## Description

This will print to screen (STDOUT) the results contained within the current data pipe.

---

### 10.2.144 results.read()

## Synopsis

Read results from a file.

## Defaults

**results.read(self, file='results', dir=None)**

## Keyword Arguments

**file:** The name of the file to read results from.

**dir:** The directory where the file is located.

## Description

This function is able to handle uncompressed, bzip2 compressed files, or gzip compressed files automatically. The full file name including extension can be supplied, however, if the file cannot be found the file with '.bz2' appended followed by the file name with '.gz' appended will be searched for.

---

### 10.2.145 results.write()

## Synopsis

Write the results to a file.

## Defaults

**results.write(self, file='results', dir='pipe\_name', compress\_type=1, force=False)**

---

### 10.2.143 results.display()

## Synopsis

Display the results.

## Keyword Arguments

**file:** The name of the file to output results to. The default is 'results'. Optionally this can be a file object, or any object with a write() method.

**dir:** The directory name.

**compress\_type:** The type of compression to use when creating the file.

**force:** A flag which if True will cause the results file to be overwritten.

## Description

To place the results file in the current working directory in the prompt and scripting modes, set dir to None. If dir is set to the special name 'pipe\_name', then the results file will be placed into a directory with the same name as the current data pipe.

The default behaviour of this function is to compress the file using bzip2 compression. If the extension '.bz2' is not included in the file name, it will be added. The compression can, however, be changed to either no compression or gzip compression. This is controlled by the compression type which can be set to

- 0 – No compression (no file extension),
- 1 – bzip2 compression ('.bz2' file extension),
- 2 – gzip compression ('.gz' file extension).

The complementary read function will automatically handle the compressed files.

---

### 10.2.146 select.all()

## Synopsis

Select all spins.

## Defaults

**select.all(self)**

## Description

This will select all spins, irregardless of their current state.

## Examples

To select all spins, simply type:

```
relax> select.all()
```

---

### 10.2.147 select.read()

## Synopsis

Select the spins contained in a file.

## Defaults

**select.read(self, file=None, dir=None, spin\_id\_col=None, mol\_name\_col=None, res\_num\_col=None, res\_name\_col=None, spin\_num\_col=None, spin\_name\_col=None, sep=None, spin\_id=None, boolean='OR', change\_all=False)**

## Keyword Arguments

**file:** The name of the file containing the list of spins to select.

**dir:** The directory where the file is located.

**spin\_id\_col:** The spin ID string column (an alternative to the mol, res, and spin name and number columns).

**mol\_name\_col:** The molecule name column (alternative to the spin\_id\_col).

**res\_num\_col:** The residue number column (alternative to the spin\_id\_col).

**res\_name\_col:** The residue name column (alternative to the spin\_id\_col).

**spin\_num\_col:** The spin number column (alternative to the spin\_id\_col).

**spin\_name\_col:** The spin name column (alternative to the spin\_id\_col).

**data\_col:** The RDC data column.

**error\_col:** The experimental error column.

**sep:** The column separator (the default is white space).

**spin\_id:** The spin ID string to restrict the loading of data to certain spin subsets.

**boolean:** The boolean operator specifying how spins should be selected.

**change\_all:** A flag specifying if all other spins should be changed.



## Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the molecule name, residue number, residue name, spin number and/or spin name columns can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The spin ID string can be used to restrict the reading to certain spin types, for example only  $^{15}\text{N}$  spins when only residue information is in the file.

Empty lines and lines beginning with a hash are ignored.

The ‘`change_all`’ flag default is False meaning that all spins currently either selected or deselected will remain that way. Setting this to True will cause all spins not specified in the file to be deselected.

## Examples

To select all residues listed with residue numbers in the first column of the file ‘`isolated_peaks`’, type one of:

```
relax> select.read('isolated_peaks',
res_num_col=1)
```

```
relax> select.read(file='isolated_peaks',
res_num_col=1)
```

To select the spins in the second column of the relaxation data file ‘`r1.600`’ while deselecting all other spins, for example type:

```
relax> select.read('r1.600', spin_num_col=2,
change_all=True)
```

```
relax> select.read(file='r1.600',
spin_num_col=2, change_all=True)
```

## Boolean operators

The boolean operator can be used to change how spin systems are selected. The allowed values are: ‘`OR`’, ‘`NOR`’, ‘`AND`’, ‘`NAND`’, ‘`XOR`’, ‘`XNOR`’. The following table details how the selections will occur for the different boolean operators.

(see table [10.31](#))

---

### 10.2.148 select.reverse()

#### Synopsis

Reversal of the spin selection for the given spins.

#### Defaults

```
select.reverse(self, spin_id=None)
```

## Keyword Arguments

`spin_id`: The spin ID string.

## Description

By supplying the spin ID string, a subset of spins can have their selection status reversed.

## Examples

To select all currently deselected spins and deselect those which are selected type:

```
relax> select.reverse()
```

---

### 10.2.149 select.spin()

#### Synopsis

Select specific spins.

#### Defaults

```
select.spin(self, spin_id=None, boolean='OR',
change_all=False)
```

## Keyword Arguments

`spin_id`: The spin ID string.

`boolean`: The boolean operator specifying how spins should be selected.

`change_all`: A flag specifying if all other spins should be changed.

## Description

The ‘`change_all`’ flag default is False meaning that all spins currently either selected or deselected will remain that way. Setting this to True will cause all spins not specified by the spin ID string to be selected.

## Examples

To select only glycines and alanines, assuming they have been loaded with the names GLY and ALA, type one of:

```
relax> select.spin(spin_id=':GLY|:ALA')
```

To select residue 5 CYS in addition to the currently selected residues, type one of:

Table 10.31: First table for the `select.read()` user function.

| Spin system        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|--------------------|---|---|---|---|---|---|---|---|---|
| Original selection | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| New selection      | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| OR                 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| NOR                | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| AND                | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NAND               | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| XOR                | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| XNOR               | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |

```

relax> select.spin(':5')
relax> select.spin(':5&:CYS')
relax> select.spin(spin_id=':5&:CYS')

```

## Boolean operators

The boolean operator can be used to change how spin systems are selected. The allowed values are: 'OR', 'NOR', 'AND', 'NAND', 'XOR', 'XNOR'. The following table details how the selections will occur for the different boolean operators.

(see table [10.32](#))

## Description

This will copy the sequence data between data pipes. The destination data pipe must not contain any sequence data. If the source and destination pipes are not specified, then both will default to the current data pipe (hence providing one is essential).

## Examples

To copy the sequence from the data pipe 'm1' to the current data pipe, type:

```

relax> sequence.copy('m1')
relax> sequence.copy(pipe_from='m1')

```

To copy the sequence from the current data pipe to the data pipe 'm9', type:

```

relax> sequence.copy(pipe_to='m9')

```

To copy the sequence from the data pipe 'm1' to 'm2', type:

```

relax> sequence.copy('m1', 'm2')
relax> sequence.copy(pipe_from='m1',
pipe_to='m2')

```

---

### 10.2.150 sequence.copy()

#### Synopsis

Copy the molecule, residue, and spin sequence data from one data pipe to another.

#### Defaults

`sequence.copy(self, pipe_from=None, pipe_to=None)`

#### Keyword Arguments

**pipe\_from:** The name of the data pipe to copy the sequence data from.

**pipe\_to:** The name of the data pipe to copy the sequence data to.

---

### 10.2.151 sequence.display()

#### Synopsis

Display sequences of molecules, residues, and/or spins.

Table 10.32: First table for the `select.spin()` user function.

| Spin system        | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|--------------------|---|---|---|---|---|---|---|---|---|
| Original selection | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 |
| New selection      | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| OR                 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 |
| NOR                | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| AND                | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| NAND               | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| XOR                | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| XNOR               | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 |

## Defaults

**sequence.display**(self, sep=None, mol\_name\_flag=True, res\_num\_flag=True, res\_name\_flag=True, spin\_num\_flag=True, spin\_name\_flag=True)

## Keyword Arguments

**sep**: The column separator (the default of None corresponds to white space).

**mol\_name\_flag**: A flag which if True will cause the molecule name column to be shown.

**res\_num\_flag**: A flag which if True will cause the residue number column to be shown.

**res\_name\_flag**: A flag which if True will cause the residue name column to be shown.

**spin\_num\_flag**: A flag which if True will cause the spin number column to be shown.

**spin\_name\_flag**: A flag which if True will cause the spin name column to be shown.

## Keyword Arguments

**file**: The name of the file containing the sequence data.

**dir**: The directory where the file is located.

**spin\_id\_col**: The spin ID string column (an alternative to the mol, res, and spin name and number columns).

**mol\_name\_col**: The molecule name column (alternative to the spin\_id\_col).

**res\_num\_col**: The residue number column (alternative to the spin\_id\_col).

**res\_name\_col**: The residue name column (alternative to the spin\_id\_col).

**spin\_num\_col**: The spin number column (alternative to the spin\_id\_col).

**spin\_name\_col**: The spin name column (alternative to the spin\_id\_col).

**sep**: The column separator (the default is white space).

**spin\_id**: The spin ID string to restrict the loading of data to certain spin subsets.

### 10.2.152 sequence.read()

## Synopsis

Read the molecule, residue, and spin sequence from a file.

## Defaults

**sequence.read**(self, file=None, dir=None, spin\_id\_col=None, mol\_name\_col=None, res\_num\_col=None, res\_name\_col=None, spin\_num\_col=None, spin\_name\_col=None, sep=None, spin\_id=None)

## Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the molecule name, residue number, residue name, spin number and/or spin name columns can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The spin ID string can be used to restrict the reading to certain spin types, for example only <sup>15</sup>N spins when only residue information is in the file.

## Examples

The following commands will read protein backbone 15N sequence data out of a file called 'seq' where the residue numbers and names are in the first and second columns respectively:

```
relax> sequence.read('seq')

relax> sequence.read('seq', res_num_col=1,
res_name_col=2)

relax> sequence.read(file='seq',
res_num_col=1, res_name_col=2, sep=None)
```

The following commands will read the residue sequence out of the file 'noe.out' which also contains the NOE values:

```
relax> sequence.read('noe.out')

relax> sequence.read('noe.out', res_num_col=
1, res_name_col=2)

relax> sequence.read(file='noe.out',
res_num_col=1, res_name_col=2)
```

The following commands will read the sequence out of the file 'noe.600.out' where the residue numbers are in the second column, the names are in the sixth column and the columns are separated by commas:

```
relax> sequence.read('noe.600.out',
res_num_col=2, res_name_col=6, sep=',')

relax> sequence.read(file='noe.600.out',
res_num_col=2, res_name_col=6, sep=',')
```

The following commands will read the RNA residues and atoms (including C2, C5, C6, C8, N1, and N3) from the file '500.NOE', where the residue number, residue name, spin number, and spin name are in the first to fourth columns respectively:

```
relax> sequence.read('500.NOE', res_num_col=
1, res_name_col=2, spin_num_col=3,
spin_name_col=4)

relax> sequence.read(file='500.NOE',
res_num_col=1, res_name_col=2, spin_num_col=
3, spin_name_col=4)
```

---

### 10.2.153 sequence.write()

#### Synopsis

Write the molecule, residue, and spin sequence to a file.

#### Defaults

```
sequence.write(self, file, dir=None, sep=None,
mol_name_flag=False, res_num_flag=False,
res_name_flag=False, spin_num_flag=False,
spin_name_flag=False, force=False)
```

## Keyword Arguments

file: The name of the file.

dir: The directory name.

sep: The column separator (the default of None corresponds to white space).

mol\_name\_flag: A flag which if True will cause the molecule name column to be shown.

res\_num\_flag: A flag which if True will cause the residue number column to be shown.

res\_name\_flag: A flag which if True will cause the residue name column to be shown.

spin\_num\_flag: A flag which if True will cause the spin number column to be shown.

spin\_name\_flag: A flag which if True will cause the spin name column to be shown.

force: A flag which if True will cause the file to be overwritten.

## Description

Write the sequence data to file. If no directory name is given, the file will be placed in the current working directory.

---

### 10.2.154 spectrum.baseplane\_rmsd()

#### Synopsis

Set the baseplane RMSD of a given spin in a spectrum for error analysis.

#### Defaults

```
spectrum.baseplane_rmsd(self, error=0.0, spectrum_id=
None, spin_id=None)
```

## Keyword Arguments

error: The baseplane RMSD error value.

spectrum\_id: The spectrum ID string.

spin\_id: The spin ID string.

## Description

The spectrum ID identifies the spectrum associated with the error and must correspond to a previously loaded set of intensities. If the spin ID is unset, then the error value for all spins will be set to the supplied value.

---

### 10.2.155 `spectrum.delete()`

#### Synopsis

Delete the spectral data corresponding to the spectrum ID string.

#### Defaults

`spectrum.delete(self, spectrum_id=None)`

#### Keyword Arguments

`spectrum_id`: The unique spectrum ID string.

## Description

The spectral data corresponding to the given spectrum ID string will be removed from the current data pipe.

## Examples

To delete the peak height data corresponding to the ID 'R1 ncyc5', type:

```
relax> spectrum.delete('R1 ncyc5')
```

---

### 10.2.156 `spectrum.error_analysis()`

#### Synopsis

Perform an error analysis for peak intensities.

#### Defaults

`spectrum.error_analysis(self)`

## Description

This user function must only be called after all peak intensities have been loaded and all other necessary spectral information set. This includes the baseplane RMSD and the number of points used in volume integration, both of which are only used if spectra have not been replicated.

Six different types of error analysis are supported depending on whether peak heights or volumes are supplied, whether noise is determined from replicated spectra or the RMSD of the baseplane noise, and whether all spectra or only a subset have been duplicated. These are:

(see table 10.33)

#### Peak heights with baseplane noise RMSD

When none of the spectra have been replicated, then the peak height errors are calculated using the RMSD of the baseplane noise, the value of which is set by the `spectrum.baseplane_rmsd()` user function. This results in a different error per peak per spectrum. The standard deviation error measure for the peak height, `sigma_I`, is set to the RMSD value.

#### Peak heights with partially replicated spectra

When spectra are replicated, the variance for a single spin at a single replicated spectra set is calculated by the formula

$$\sigma^2 = \text{sum}(\{I_i - I_{av}\}^2) / (n - 1) ,$$

where  $\sigma^2$  is the variance,  $\sigma$  is the standard deviation,  $n$  is the size of the replicated spectra set with  $i$  being the corresponding index,  $I_i$  is the peak intensity for spectrum  $i$ , and  $I_{av}$  is the mean over all spectra i.e. the sum of all peak intensities divided by  $n$ .

As the value of  $n$  in the above equation is always very low since normally only a couple of spectra are collected per replicated spectra set, the variance of all spins is averaged for a single replicated spectra set. Although this results in all spins having the same error, the accuracy of the error estimate is significantly improved.

If there are in addition to the replicated spectra loaded peak intensities which only consist of a single spectrum, i.e. not all spectra are replicated, then the variances of replicated spectra sets will be averaged. This will be used for the entire experiment so that there will be only a single error value for all spins and for all spectra.

Table 10.33: First table for the `spectrum.error_analysis()` user function.

| Int type | Noise source                           | Error scope                          |
|----------|----------------------------------------|--------------------------------------|
| Heights  | RMSD baseplane                         | One sigma per peak per spectrum      |
| Heights  | Partial duplicate + variance averaging | One sigma for all peaks, all spectra |
| Heights  | All replicated + variance averaging    | One sigma per replicated spectra set |
| Volumes  | RMSD baseplane                         | One sigma per peak per spectrum      |
| Volumes  | Partial duplicate + variance averaging | One sigma for all peaks, all spectra |
| Volumes  | All replicated + variance averaging    | One sigma per replicated spectra set |

### Peak heights with all spectra replicated

If all spectra are collected in duplicate (triplicate or higher number of spectra are supported), the each replicated spectra set will have its own error estimate. The error for a single peak is calculated as when partially replicated spectra are collected, and these are again averaged to give a single error per replicated spectra set. However as all replicated spectra sets will have their own error estimate, variance averaging across all spectra sets will not be performed.

### Peak volumes with baseplane noise RMSD

The method of error analysis when no spectra have been replicated and peak volumes are used is highly dependent on the integration method. Many methods simply sum the number of points within a fixed region, either a box or oval object. The number of points used,  $N$ , must be specified by another user function in this class. Then the error is simply given by the sum of variances:

$$\text{sigma\_vol}^2 = \text{sigma\_i}^2 * N,$$

where  $\text{sigma\_vol}$  is the standard deviation of the volume,  $\text{sigma\_i}$  is the standard deviation of a single point assumed to be equal to the RMSD of the baseplane noise, and  $N$  is the total number of points used in the summation integration method. For a box integration method, this converts to the Nicholson, Kay, Baldisseri, Arango, Young, Bax, and Torchia (1992) Biochemistry, 31: 5253-5263 equation:

$$\text{sigma\_vol} = \text{sigma\_i} * \sqrt{n*m},$$

where  $n$  and  $m$  are the dimensions of the box. Note that a number of programs, for example peakint ([http://hugin.ethz.ch/wuthrich/software/xeasy/xeasy\\_m15.html](http://hugin.ethz.ch/wuthrich/software/xeasy/xeasy_m15.html)) does not use all points within the box. And if the number  $N$  can not be determined, this category of error analysis is not possible.

Also note that non-point summation methods, for example when line shape fitting is used to determine peak volumes, the equations above cannot be used. Hence again this category of error analysis cannot be used. This is the case for one of the three integration methods used by Sparky (<http://www.cgl.ucsf.edu/home/sparky/manual/peaks.html#Integration>). And if fancy techniques are used, for example as Cara does to deconvolute overlapping peaks (<http://www.cara.ethz.ch/Wiki/Integration>), this again makes this error analysis impossible.

### Peak volumes with partially replicated spectra

When peak volumes are measured by any integration method and a few of the spectra are replicated, then the intensity errors are calculated identically as described in the 'Peak heights with partially replicated spectra' section above.

### Peak volumes with all spectra replicated

With all spectra replicated and again using any integration methodology, the intensity errors can be calculated as described in the 'Peak heights with all spectra replicated' section above.

### 10.2.157 `spectrum.integration_points()`

#### Synopsis

Set the number of summed points used in volume integration of a given spin in a spectrum.

#### Defaults

`spectrum.integration_points(self, N=None, spectrum_id=None, spin_id=None)`

#### Keyword Arguments

**N:** The number of points used by the summation volume integration method.

**spectrum\_id:** The spectrum ID string.

**spin\_id:** The spin ID string.

#### Description

For a complete description of which integration methods and how many points *N* are used for different integration techniques, please see the `spectrum.error-analysis` user function documentation.

The spectrum ID identifies the spectrum associated with the value of *N* and must correspond to a previously loaded set of intensities. If the spin ID is unset, then the number of summed points for all spins will be set to the supplied value.

#### Keyword Arguments

**file:** The name of the file containing the intensity data.

**dir:** The directory where the file is located.

**spectrum\_id:** The unique spectrum ID string.

**heteronuc:** The name of the heteronucleus as specified in the peak intensity file.

**proton:** The name of the proton as specified in the peak intensity file.

**int\_method:** The integration method.

**int\_col:** The optional column containing the peak intensity data (used by the generic intensity file format, or if the intensities are in a non-standard column).

**spin\_id\_col:** The spin ID string column used by the generic intensity file format (an alternative to the `mol`, `res`, and `spin` name and number columns).

**mol\_name\_col:** The molecule name column used by the generic intensity file format (alternative to the `spin ID` column).

**res\_num\_col:** The residue number column used by the generic intensity file format (alternative to the `spin ID` column).

**res\_name\_col:** The residue name column used by the generic intensity file format (alternative to the `spin ID` column).

**spin\_num\_col:** The spin number column used by the generic intensity file format (alternative to the `spin ID` column).

**spin\_name\_col:** The spin name column used by the generic intensity file format (alternative to the `spin ID` column).

**sep:** The column separator used by the generic intensity format (the default is white space).

**spin\_id:** The spin ID string used by the generic intensity file format to restrict the loading of data to certain spin subsets.

**ncproc:** The Bruker specific FID intensity scaling factor.

#### Description

The peak intensity can either be from peak heights or peak volumes.

The spectrum ID is a label which is subsequently utilised by other user functions. If this identifier matches that of a previously loaded set of intensities, then this indicates a replicated spectrum.

The heteronucleus and proton should be set respectively to the name of the heteronucleus and proton in the file. Only those lines which match these labels will be used.

---

### 10.2.158 `spectrum.read_intensities()`

#### Synopsis

Read peak intensities from a file.

#### Defaults

`spectrum.read_intensities(self, file=None, dir=None, spectrum_id=None, heteronuc='N', proton='HN', int_method='height', int_col=None, spin_id_col=None, mol_name_col=None, res_num_col=None, res_name_col=None, spin_num_col=None, spin_name_col=None, sep=None, spin_id=None, ncproc=None)`



The integration method is required for the subsequent error analysis. When peak heights are measured, this should be set to `'height'`. Volume integration methods are a bit varied and hence two values are accepted. If the volume integration involves pure point summation, with no deconvolution algorithms or other methods affecting peak heights, then the value should be set to `'point sum'`. All other volume integration methods, e.g. line shape fitting, the value should be set to `'other'`.

If a series of intensities extracted from Bruker FID files processed in Topspin or XWinNMR are to be compared, the `ncproc` parameter may need to be supplied. This is because this FID is stored using integer representation and is scaled using `ncproc` to avoid numerical truncation artifacts. If two spectra have significantly different maximal intensities, then `ncproc` will be different for both. The intensity scaling is binary, i.e.  $2^{**ncproc}$ . Therefore if spectrum A has an `ncproc` of 6 and spectrum B a value of 7, then a reference intensity in B will be double that of A. Internally, `relax` stores the intensities scaled by  $2^{**ncproc}$ .

## Examples

To read the reference and saturated spectra peak heights from the Sparky formatted files `'ref.list'` and `'sat.list'`, type:

```
relax> spectrum.read_intensities(file='ref.
list', spectrum_id='ref')

relax> spectrum.read_intensities(file='sat.
list', spectrum_id='sat')
```

To read the reference and saturated spectra peak heights from the XEasy formatted files `'ref.text'` and `'sat.text'`, type:

```
relax> spectrum.read_intensities(file='ref.
text', spectrum_id='ref')

relax> spectrum.read_intensities(file='sat.
text', spectrum_id='sat')
```

## File formats

The peak list or intensity file will be automatically determined.

**Sparky peak list:** The file should be a Sparky peak list saved after typing the command `'lt'`. The default is to assume that columns 0, 1, 2, and 3 (1<sup>st</sup>, 2<sup>nd</sup>, 3<sup>rd</sup>, and 4<sup>th</sup>) contain the Sparky assignment, w1, w2, and peak intensity data respectively. The frequency data w1 and w2 are ignored while the peak intensity data can either be the peak height or volume displayed by changing the window options. If the peak intensity data is not within column 3, set the integration column to the appropriate number (column numbering starts from 0 rather than 1).

**XEasy peak list:** The file should be the saved XEasy text window output of the list peak entries command, `'tw'` followed by `'le'`. As the columns are fixed, the peak intensity column is hardwired to number 10 (the 11<sup>th</sup> column) which contains either the peak height or peak volume data. Because the columns are fixed, the integration column number will be ignored.

**NMRView:** The file should be a NMRView peak list. The default is to use column 16 (which contains peak heights) for peak intensities. To use use peak volumes (or evolumes), `int_col` must be set to 15.

**Generic intensity file:** This is a generic format which can be created by scripting to support non-supported peak lists. It should contain in the first few columns enough information to identify the spin. This can include columns for the molecule name, residue number, residue name, spin number, and spin name. Alternatively a spin ID string column can be used. The peak intensities can be placed in another column specified by the integration column number. Intensities from multiple spectra can be placed into different columns, and these can then be specified simultaneously by setting the integration column value to a list of columns. This list must be matched by setting the spectrum ID to a list of the same length. If columns are delimited by a character other than whitespace, this can be specified with the column separator. The spin ID can be used to restrict the loading to specific spin subsets.

---

### 10.2.159 spectrum.replicated()

#### Synopsis

Specify which spectra are replicates of each other.

#### Defaults

`spectrum.replicated(self, spectrum_ids=None)`

#### Keyword Arguments

`spectrum_ids`: The list of replicated spectra ID strings.

#### Description

This is used to identify which of the loaded spectra are replicates of each other. Specifying the replicates is essential for error analysis if the baseplane RMSD has not been supplied.

#### Examples

To specify that the NOE spectra labelled `'ref1'`, `'ref2'`, and `'ref3'` are the same spectrum replicated, type one of:

```
relax> spectrum.replicated(['ref1', 'ref2',
' ref3'])
```

```
relax> spectrum.replicated(spectrum_ids=
['ref1', 'ref2', 'ref3'])
```

To specify that the two R<sub>2</sub> spectra `'ncyc2'` and `'ncyc2b'` are the same time point, type:



```
relax> spectrum.replicated(['ncyc2',
                           'ncyc2b'])
```

---

### 10.2.160 spin.copy()

#### Synopsis

Copy all data associated with a spin.

#### Defaults

**spin.copy**(self, pipe\_from=None, spin\_from=None, pipe\_to=None, spin\_to=None)

#### Keyword Arguments

**pipe\_from**: The data pipe containing the spin from which the data will be copied. This defaults to the current data pipe.

**spin\_from**: The spin identifier string of the spin to copy the data from.

**pipe\_to**: The data pipe to copy the data to. This defaults to the current data pipe.

**spin\_to**: The spin identifier string of the spin to copy the data to.

#### Description

This will copy all the data associated with the identified spin to the new, non-existent spin. The new spin must not already exist.

#### Examples

To copy the spin data from spin 1 to the new spin 2, type:

```
relax> spin.copy(spin_from='@1', spin_to='@2')
```

To copy spin 1 of the molecule 'Old mol' to spin 5 of the molecule 'New mol', type:

```
relax> spin.copy(spin_from='#Old mol@1',
                 spin_to='#New mol@5')
```

To copy the spin data of spin 1 from the data pipe 'm1' to 'm2', assuming the current data pipe is 'm1', type:

```
relax> spin.copy(spin_from='@1', pipe_to='m2')
```

```
relax> spin.copy(pipe_from='m1', spin_from='@1',
                 pipe_to='m2', spin_to='@1')
```

---

### 10.2.161 spin.create()

#### Synopsis

Create a new spin.

#### Defaults

**spin.create**(self, spin\_num=None, spin\_name=None, res\_num=None, res\_name=None, mol\_name=None)

#### Keyword Arguments

**spin\_num**: The spin number.

**spin\_name**: The name of the spin.

**res\_num**: The number of the residue to add the spin to.

**res\_name**: The name of the residue to add the spin to.

**mol\_name**: The name of the molecule to add the spin to.

#### Description

This will add a new spin data container to the relax data storage object. The same spin number cannot be used more than once.

#### Examples

The following sequence of commands will generate the sequence 1 C4, 2 C9, 3 C15:

```
relax> spin.create(1, 'C4')
```

```
relax> spin.create(2, 'C9')
```

```
relax> spin.create(3, 'C15')
```

---

### 10.2.162 spin.create\_pseudo()

#### Synopsis

Create a spin system representing a pseudo-atom.

#### Defaults

**spin.create\_pseudo**(self, spin\_name=None, spin\_num=None, res\_id=None, members=None, averaging='linear')

## Keyword Arguments

**spin\_name:** The name of the pseudo-atom spin.

**spin\_num:** The spin number.

**res\_id:** The molecule and residue ID string identifying the position to add the pseudo-spin to.

**members:** A list of the atoms (as spin ID strings) that the pseudo-atom is composed of.

**averaging:** The positional averaging technique.

## Description

This will create a spin data container representing a number of pre-existing spin containers as a pseudo-atom. The optional spin number must not already exist.

## Examples

The following will create the pseudo-atom named 'Q9' consisting of the protons '@H16', '@H17', '@H18':

```
relax> spin.create_pseudo('Q9', members=
['@H16', '@H17', '@H18'])
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]', where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

## 10.2.163 spin.delete()

### Synopsis

Delete spins.

### Defaults

**spin.delete**(self, spin\_id=None)

## Keyword Arguments

**spin\_id:** The spin identifier string.

## Description

This can be used to delete a single or sets of spins. See the identification string documentation below for more information.

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is '#<mol\_name> :<res\_id>[, <res\_id>[, <res\_id>, ...]] @<atom\_id>[, <atom\_id>[, <atom\_id>, ...]]', where the token elements are '<mol\_name>', the name of the molecule, '<res\_id>', the residue identifier which can be a number, name, or range of numbers, '<atom\_id>', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

## 10.2.164 spin.display()

### Synopsis

Display information about the spin(s).

## Defaults

`spin.display(self, spin_id=None)`

## Keyword Arguments

`spin_id`: The spin identification string.

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

## Description

This allows the element type of the spins to be set.

## Examples

The set all spins of residue 1 to be carbons, type one of:

```
relax> spin.element('@1', 'C', force=True)
relax> spin.element(spin_id='@1', element='C', force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.165 spin.element()

#### Synopsis

Set the element type of the spin.

#### Defaults

`spin.element(self, spin_id=None, element=None, force=False)`

#### Keyword Arguments

`spin_id`: The spin identification string corresponding to one or more spins.

`element`: The IUPAC element name.

`force`: A flag which if True will cause the element to be changed.

---

### 10.2.166 spin.name()

#### Synopsis

Name the spins.

#### Defaults

`spin.name(self, spin_id=None, name=None, force=False)`

## Keyword Arguments

**spin\_id:** The spin identification string corresponding to one or more spins.

**name:** The new name.

**force:** A flag which if True will cause the spin to be renamed.

## Description

This simply allows spins to be named (or renamed). Spin naming often essential. For example when reading Sparky peak list files, then the spin name must match that in the file.

## Examples

The following sequence of commands will rename the sequence {1 C1, 2 C2, 3 C3} to {1 C11, 2 C12, 3 C13}:

```
relax> spin.name('@1', 'C11', force=True)
relax> spin.name('@2', 'C12', force=True)
relax> spin.name('@3', 'C13', force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

## 10.2.167 spin.number()

### Synopsis

Number the spins.

### Defaults

**spin.number**(self, spin\_id=None, number=None, force=False)

### Keyword Arguments

**spin\_id:** The spin identification string corresponding to a single spin.

**number:** The new spin number.

**force:** A flag which if True will cause the spin to be renumbered.

### Description

This simply allows spins to be numbered. The new number cannot correspond to an existing spin number.

## Examples

The following sequence of commands will renumber the sequence {1 C1, 2 C2, 3 C3} to {-1 C1, -2 C2, -3 C3}:

```
relax> spin.number('@1', -1, force=True)
relax> spin.number('@2', -2, force=True)
relax> spin.number('@3', -3, force=True)
```

## Spin ID string documentation

The identification string is composed of three components: the molecule id token beginning with the '#' character, the residue id token beginning with the ':' character, and the atom or spin system id token beginning with the '@' character. Each token can be composed of multiple elements separated by the ',' character and each individual element can either be a number (which must be an integer, in string format), a name, or a range of numbers separated by the '-' character. Negative numbers are supported. The full id string specification is `'#<mol_name> :<res_id>[, <res_id>[, <res_id>, ...]] @<atom_id>[, <atom_id>[, <atom_id>, ...]]'`, where the token elements are '`<mol_name>`', the name of the molecule, '`<res_id>`', the residue identifier which can be a number, name, or range of numbers, '`<atom_id>`', the atom or spin system identifier which can be a number, name, or range of numbers.

If one of the tokens is left out then all elements will be assumed to match. For example if the string does not

contain the '#' character then all molecules will match the string.

Regular expression can be used to select spins. For example the string '@H\*' will select the protons 'H', 'H2', 'H98'.

---

### 10.2.168 state.load()

#### Synopsis

Function for loading a saved program state.

#### Defaults

**state.load**(self, state=None, dir=None, force=False)

#### Keyword Arguments

**state**: The file name, which can be a string or a file descriptor object, of a saved program state.

**dir**: The name of the directory in which the file is found.

**force**: A boolean flag which if True will cause the current program state to be overwritten.

#### Description

This function is able to handle uncompressed, bzip2 compressed files, or gzip compressed files automatically. The full file name including extension can be supplied, however, if the file cannot be found, this function will search for the file name with '.bz2' appended followed by the file name with '.gz' appended.

Both the XML and pickled saved state formats are supported and automatically determined. For more advanced users, file descriptor objects are also supported. If the force flag is set to True, then the relax data store will be reset prior to the loading of the saved state.

#### Examples

The following commands will load the state saved in the file 'save'.

```
relax> state.load('save')
relax> state.load(state='save')
```

Use one of the following commands to load the state saved in the bzip2 compressed file 'save.bz2':

```
relax> state.load('save')
relax> state.load(state='save')
relax> state.load('save.bz2')
```

```
relax> state.load(state='save.bz2', force=
True)
```

---

### 10.2.169 state.save()

#### Synopsis

Function for saving the program state.

#### Defaults

**state.save**(self, state=None, dir=None, compress\_type=1, force=False, pickle=False)

#### Keyword Arguments

**state**: The file name, which can be a string or a file descriptor object, to save the current program state in.

**dir**: The name of the directory in which to place the file.

**compress\_type**: The type of compression to use when creating the file.

**force**: A boolean flag which if set to True will cause the file to be overwritten.

**pickle**: A flag which if true will cause the state file to be a pickled object rather than the default XML format.

#### Description

This user function will place the program state - the relax data store - into a file for later reloading or reference. The default format is an XML formatted file, but this can be changed to a Python pickled object through the pickle flag. Note, the pickle format is not human readable and often is not compatible with newer relax versions.

The default behaviour of this function is to compress the file using bzip2 compression. If the extension '.bz2' is not included in the file name, it will be added. The compression can, however, be changed to either no compression or gzip compression. This is controlled by the compress\_type argument which can be set to

- 0 – No compression (no file extension).
- 1 – bzip2 compression ('.bz2' file extension).
- 2 – gzip compression ('.gz' file extension).

## Examples

The following commands will save the current program state, uncompressed, into the file 'save':

```
relax> state.save('save', compress_type=0)

relax> state.save(state='save',
compress_type=0)
```

The following commands will save the current program state into the bzip2 compressed file 'save.bz2':

```
relax> state.save('save')

relax> state.save(state='save')

relax> state.save('save.bz2')

relax> state.save(state='save.bz2')
```

If the file 'save' already exists, the following commands will save the current program state by overwriting the file.

```
relax> state.save('save', force=True)

relax> state.save(state='save', force=True)
```

---

## 10.2.170 structure.add\_atom()

### Synopsis

Add an atom.

### Defaults

```
structure.add_atom(self, atom_name=None, res_name=
None, res_num=None, pos=[None, None, None],
element=None, atom_num=None, chain_id=None,
segment_id=None, pdb_record=None)
```

### Keyword Arguments

**atom\_name**: The atom name.

**res\_name**: The residue name.

**res\_num**: The residue number.

**pos**: The atomic coordinates.

**element**: The element name.

**atom\_num**: The optional atom number.

**chain\_id**: The optional chain ID string.

**segment\_id**: The optional segment ID string.

**pdb\_record**: The optional PDB record name, e.g. 'ATOM' or 'HETATM'.

## Description

This allows atoms to be added to the internal structural object.

---

## 10.2.171 structure.connect\_atom()

### Synopsis

Connect two atoms.

### Defaults

```
structure.connect_atom(self, index1=None, index2=
None)
```

### Keyword Arguments

**index1**: The global index of the first atom.

**index2**: The global index of the second atom.

## Description

This allows atoms to be connected in the internal structural object. The global index is normally equal to the PDB atom number minus 1.

---

## 10.2.172 structure.create\_diff\_tensor\_pdb()

### Synopsis

Create a PDB file to represent the diffusion tensor.

### Defaults

```
structure.create_diff_tensor_pdb(self, scale=1.8e-06, file=
'tensor.pdb', dir=None, force=False)
```

### Keyword Arguments

**scale**: Value for scaling the diffusion rates.

**file**: The name of the PDB file.

**dir**: The directory where the file is located.

**force**: A flag which, if set to True, will overwrite the any pre-existing file.

## Description

This creates a PDB file containing an artificial geometric structure to represent the diffusion tensor. A structure must have previously been read into relax. The diffusion tensor is represented by an ellipsoidal, spheroidal, or spherical geometric object with its origin located at the centre of mass (of the selected residues). This diffusion tensor PDB file can subsequently be read into any molecular viewer.

There are four different types of residue within the PDB. The centre of mass of the selected residues is represented as a single carbon atom of the residue 'COM'. The ellipsoidal geometric shape consists of numerous H atoms of the residue 'TNS'. The axes of the tensor, when defined, are presented as the residue 'AXS' and consist of carbon atoms: one at the centre of mass and one at the end of each eigenvector. Finally, if Monte Carlo simulations were run and the diffusion tensor parameters were allowed to vary then there will be multiple 'SIM' residues, one for each simulation. These are essentially the same as the 'AXS' residue, representing the axes of the simulated tensors, and they will appear as a distribution.

As the Brownian rotational diffusion tensor is a measure of the rate of rotation about different axes - the larger the geometric object, the faster the diffusion of a molecule. For example the diffusion tensor of a water molecule is much larger than that of a macromolecule.

The effective global correlation time experienced by an XH bond vector, not to be confused with the Lipari and Szabo parameter  $\tau_c$ , will be approximately proportional to the component of the diffusion tensor parallel to it. The approximation is not exact due to the multiexponential form of the correlation function of Brownian rotational diffusion. If an XH bond vector is parallel to the longest axis of the tensor, it will be unaffected by rotations about that axis, which are the fastest rotations of the molecule, and therefore its effective global correlation time will be maximal.

To set the size of the diffusion tensor within the PDB frame the unit vectors used to generate the geometric object are first multiplied by the diffusion tensor (which has the units of inverse seconds) then by the scaling factor (which has the units of second Å and has the default value of  $1.8\text{e-}6\text{ s}\cdot\text{Angstrom}$ ). Therefore the rotational diffusion rate per Å is equal to the inverse of the scale value (which defaults to  $5.56\text{e}5\text{ s}^{-1}\cdot\text{Angstrom}^{-1}$ ). Using the default scaling value for spherical diffusion, the correspondence between global correlation time,  $\mathfrak{D}_{iso}$  diffusion rate, and the radius of the sphere for a number of discrete cases will be:

(see table 10.34)

The scaling value has been fixed to facilitate comparisons within or between publications, but can be changed to vary the size of the tensor geometric object if necessary. Reporting the rotational diffusion rate per Å within figure legends would be useful.

To create the tensor PDB representation, a number of algorithms are utilised. Firstly the centre of mass is calculated for the selected residues and is represented in the PDB by a C atom. Then the axes of the diffusion are calculated, as unit vectors scaled to the appropriate length (multiplied by the eigenvalue  $\mathfrak{D}_x$ ,  $\mathfrak{D}_y$ ,  $\mathfrak{D}_z$ ,  $\mathfrak{D}_{||}$ ,  $\mathfrak{D}_{\perp}$ , or

$\mathfrak{D}_{iso}$  as well as the scale value), and a C atom placed at the position of this vector plus the centre of mass. Finally a uniform distribution of vectors on a sphere is generated using spherical coordinates. By incrementing the polar angle using an arccos distribution, a radial array of vectors representing latitude are created while incrementing the azimuthal angle evenly creates the longitudinal vectors. These unit vectors, which are distributed within the PDB frame and are of 1 Å in length, are first rotated into the diffusion frame using a rotation matrix (the spherical diffusion tensor is not rotated). Then they are multiplied by the diffusion tensor matrix to extend the vector out to the correct length, and finally multiplied by the scale value so that the vectors reasonably superimpose onto the macromolecular structure. The last set of algorithms place all this information into a PDB file. The distribution of vectors are represented by H atoms and are all connected using PDB CONECT records. Each H atom is connected to its two neighbours on both the longitude and latitude. This creates a geometric PDB object with longitudinal and latitudinal lines.

---

### 10.2.173 structure.create\_vector\_dist()

#### Synopsis

Create a PDB file representation of the distribution of XH bond vectors.

#### Defaults

`structure.create_vector_dist(self, length=2e-09, file='XH_dist.pdb', dir=None, symmetry=True, force=False)`

#### Keyword Arguments

**length:** The length of the vectors in the PDB representation (meters).

**file:** The name of the PDB file.

**dir:** The directory to place the file into.

**symmetry:** A flag which if True will create a second chain with reversed XH bond orientations.

**force:** A flag which if True will overwrite the file if it already exists.

## Description

This creates a PDB file containing an artificial vectors, the length of which default to the length argument of 20 Å. A structure must have previously been read into relax. The origin of the vector distribution is located at the centre of mass (of the selected residues). This vector distribution PDB file can subsequently be read into any molecular viewer.



Table 10.34: First table for the `structure.create_diff_tensor_pdb()` user function.

| $\tau_m$ (ns) | $\mathfrak{D}_{iso}$ ( $s^{-1}$ ) | Radius ( $\text{\AA}$ ) |
|---------------|-----------------------------------|-------------------------|
| 1             | 1.67e8                            | 300                     |
| 3             | 5.56e7                            | 100                     |
| 10            | 1.67e7                            | 30                      |
| 30            | 5.56e6                            | 10                      |

Because of the symmetry of the diffusion tensor reversing the orientation of the XH bond vector has no effect. Therefore by setting the symmetry flag two chains ‘A’ and ‘B’ will be added to the PDB file whereby chain ‘B’ is chain ‘A’ with the XH bonds reversed.

## Defaults

`structure.displacement(self, model_from=None, model_to=None, atom_id=None, centroid=None)`

## Keyword Arguments

`model_from`: The optional model number for the starting position of the displacement.

`model_to`: The optional model number for the ending position of the displacement.

`atom_id`: The atom identification string.

`centroid`: The alternative position of the centroid.

## Description

This user function allows the rotational and translational displacement between two models of the same structure to be calculated. The information will be printed out in various formats and held in the relax data store. This is directional, so there is a starting and ending position for each displacement. If the starting and ending models are not specified, then the displacements in all directions between all models will be calculated.

The atom ID, which uses the same notation as the spin ID strings, can be used to restrict the displacement calculation to certain molecules, residues, or atoms. This is useful if studying domain motions, secondary structure rearrangements, amino acid side chain rotations, etc.

By supplying the position of the centroid, an alternative position than the standard rigid body centre is used as the focal point of the motion. The allows, for example, a pivot of a rotational domain motion to be specified. This is not a formally correct algorithm, all translations will be zero, but does give an indication to the amplitude of the pivoting angle.

## Examples

To determine the rotational and translational displacements between all sets of models, type:

```
relax> structure.displacement()
```

## 10.2.174 structure.delete()

### Synopsis

Delete all structural information.

### Defaults

`structure.delete(self)`

### Description

This will delete all the structural information from the current data pipe. All spin and sequence information loaded from these structures will be preserved - this only affects the structural data.

### Examples

Simply type:

```
relax> structure.delete()
```

## 10.2.175 structure.displacement()

### Synopsis

Determine the rotational and translational displacement between a set of models.



To determine the displacement from model 5 to all other models, type:

```
relax> structure.displacement(model_from=5)
```

To determine the displacement of all models to model 5, type:

```
relax> structure.displacement(model_to=5)
```

To determine the displacement of model 2 to model 3, type one of:

```
relax> structure.displacement(2, 3)
```

```
relax> structure.displacement(model_from=2,
model_to=3)
```

---

## 10.2.176 structure.get\_pos()

### Synopsis

Extract the atomic positions from the loaded structures for the given spins.

### Defaults

```
structure.get_pos(self, spin_id=None, ave_pos=True)
```

### Keyword Arguments

**spin\_id**: The spin identification string.

**ave\_pos**: A flag specifying if the position of the atom is to be averaged across models.

### Description

This allows the atomic positions of the spins to be extracted from the loaded structures. This is automatically performed by the `structure.load_spins()` user function, but if the sequence information is generated in other ways, this user function allows the structural information to be obtained.

If averaging the atomic positions, then average position of all models will be loaded into the spin container. Otherwise the positions from all models will be loaded separately.

### Examples

For a model-free backbone amide nitrogen analysis whereby the N spins have already been created, to obtain the backbone N positions from the file '1F3Y.pdb' (which is a single protein), type the following two user functions:

```
relax> structure.read_pdb('1F3Y.pdb')
```

```
relax> structure.get_pos(spin_id='@N')
```

---

## 10.2.177 structure.load\_spins()

### Synopsis

Load spins from the structure into the relax data store.

### Defaults

```
structure.load_spins(self, spin_id=None, ave_pos=True)
```

### Keyword Arguments

**spin\_id**: The spin identification string.

**ave\_pos**: A flag specifying if the position of the atom is to be averaged across models.

### Description

This allows a sequence to be generated within the relax data store using the atomic information from the structure already associated with this data pipe. The spin ID string is used to select which molecules, which residues, and which atoms will be recognised as spin systems within relax. If the spin ID is left unspecified, then all molecules, residues, and atoms will be placed within the data store (and all atoms will be treated as spins).

If averaging the atomic positions, then average position of all models will be loaded into the spin container. Otherwise the positions from all models will be loaded separately.

### Examples

For a model-free backbone amide nitrogen analysis, to load just the backbone N sequence from the file '1F3Y.pdb' (which is a single protein), type the following two user functions:

```
relax> structure.read_pdb('1F3Y.pdb')
```

```
relax> structure.load_spins(spin_id='@N')
```

For an RNA analysis of adenine C8 and C2, guanine C8 and N1, cytidine C5 and C6, and uracil N3, C5, and C6, type the following series of commands (assuming that the PDB file with this atom naming has already been read):

```
relax> structure.load_spins(spin_id=":A@C8")
```

```
relax> structure.load_spins(spin_id=":A@C2")
```

```
relax> structure.load_spins(spin_id=":G@C8")
```

```
relax> structure.load_spins(spin_id=":G@N1")
```

```

relax> structure.load_spins(spin_id=":C@C5")
relax> structure.load_spins(spin_id=":C@C6")
relax> structure.load_spins(spin_id=":U@N3")
relax> structure.load_spins(spin_id=":U@C5")
relax> structure.load_spins(spin_id=":U@C6")

```

Alternatively using some Python programming:

```

relax> for id in [":A@C8", ":A@C2", ":G@C8",
":G@N1", ":C@C5", ":C@C6", ":U@N3", ":U@C5",
":U@C6"]:
relax> structure.load_spins(spin_id=id)

```

## Description

The reading of PDB files into relax is quite a flexible procedure allowing for both models, defined as an ensemble of the same molecule but with different atomic positions, and different molecules within the same model. One of more molecules can exist in one or more models. The flexibility allows PDB models to be converted into different molecules and different PDB files loaded as the same molecule but as different models.

A few different PDB parsers can be used to read the structural data. The choice of which to use depends on whether your PDB file is supported by that reader. These are selected by setting the 'parser' argument to one of:

'internal' - a fast PDB parser built into relax.

'scientific' - the Scientific Python PDB parser.

### 10.2.178 structure.read\_pdb()

## Synopsis

Reading structures from PDB files.

## Defaults

**structure.read\_pdb**(self, file=None, dir=None, read\_mol=None, set\_mol\_name=None, read\_model=None, set\_model\_num=None, parser='internal')

## Keyword Arguments

**file**: The name of the PDB file.

**dir**: The directory where the file is located.

**read\_mol**: If set, only the given molecule(s) will be read. The molecules are determined differently by the different parsers, but are numbered consecutively from 1. If unset, then all molecules will be loaded. By providing a list of numbers such as [1, 2], multiple molecules will be read.

**set\_mol\_name**: Set the names of the read molecules. If unset, then the molecules will be automatically labelled based on the file name or other information. This can either be a single name or a list of names.

**read\_model**: If set, only the given model number(s) from the PDB file will be read. This can be a single number or list of numbers.

**set\_model\_num**: Set the model numbers of the loaded molecules. If unset, then the PDB model numbers will be preserved if they exist. This can be a single number or list of numbers.

**parser**: The PDB parser used to read the file.

In a PDB file, the models are specified by the MODEL PDB record. All the supported PDB readers in relax recognise this. The molecule level is quite different between the Scientific Python and internal readers. For how Scientific Python defines molecules, please see its documentation. The internal reader is far simpler as it defines molecules using the TER PDB record. In both cases, the molecules will be numbered consecutively from 1.

Setting the molecule name allows the molecule within the PDB (within one model) to have a custom name. If not set, then the molecules will be named after the file name, with the molecule number appended if more than one exists.

Note that relax will complain if it cannot work out what to do.

This is able to handle uncompressed, bzip2 compressed files, or gzip compressed files automatically. The full file name including extension can be supplied, however, if the file cannot be found, this function will search for the file name with '.bz2' appended followed by the file name with '.gz' appended.

## Examples

To load all structures from the PDB file 'test.pdb' in the directory '~/pdb', including all models and all molecules, type one of:

```
relax> structure.read_pdb('test.pdb',
'~/pdb')
```

```
relax> structure.read_pdb(file='test.pdb',
dir='pdb')
```

To load the 10<sup>th</sup> model from the file 'test.pdb' using the Scientific Python PDB parser and naming it 'CaM', use one of:

```
relax> structure.read_pdb('test.pdb',
read_model=10, set_mol_name='CaM', parser=
'scientific')
```

```
relax> structure.read_pdb(file='test.pdb',
read_model=10, set_mol_name='CaM', parser=
'scientific')
```

To load models 1 and 5 from the file 'test.pdb' as two different structures of the same model, type one of:

```
relax> structure.read_pdb('test.pdb',
read_model=[1, 5], set_model_num=[1, 1])

relax> structure.read_pdb('test.pdb',
set_mol_name=['CaM_1', 'CaM_2'], read_model=
[1, 5], set_model_num=[1, 1])
```

To load the files 'lactose\_MCM4\_S1\_1.pdb', 'lactose\_MCM4\_S1\_2.pdb', 'lactose\_MCM4\_S1\_3.pdb' and 'lactose\_MCM4\_S1\_4.pdb' as models, type the following sequence of commands:

```
relax> structure.read_pdb(
'lactose_MCM4_S1_1.pdb', set_mol_name=
'lactose_MCM4_S1', set_model_num=1)

relax> structure.read_pdb(
'lactose_MCM4_S1_2.pdb', set_mol_name=
'lactose_MCM4_S1', set_model_num=2)

relax> structure.read_pdb(
'lactose_MCM4_S1_3.pdb', set_mol_name=
'lactose_MCM4_S1', set_model_num=3)

relax> structure.read_pdb(
'lactose_MCM4_S1_4.pdb', set_mol_name=
'lactose_MCM4_S1', set_model_num=4)
```

---

## 10.2.179 structure.read\_xyz()

### Synopsis

The XYZ loading function.

### Defaults

```
structure.read_xyz(self, file=None, dir=None, read_mol=
None, set_mol_name=None, read_model=None,
set_model_num=None)
```

### Keyword Arguments

file: The name of the XYZ file.

dir: The directory where the file is located.

read\_mol: If set, only the given molecule(s) will be read.

set\_mol\_name: Set the names of the read molecules.

read\_model: If set, only the given model number(s) from the XYZ file will be read.

set\_model\_num: Set the model numbers of the read molecules.

### Description

The XYZ files with different models, which defined as an ensemble of the same molecule but with different atomic positions, can be read into relax. If there are several molecules in one xyz file, please separate them into different files and then load them individually. Loading different models and different molecules is controlled by the four keyword arguments 'read\_mol', 'set\_mol\_name', 'read\_model', and 'set\_model\_num'.

The 'set\_mol\_name' argument is used to name the molecules within the XYZ (within one model). If not set, then the molecules will be named after the file name, with the molecule number appended if more than one exists.

Note that relax will complain if it cannot work out what to do.

### Examples

To load all structures from the XYZ file 'test.xyz' in the directory '~/xyz', including all models and all molecules, type one of:

```
relax> structure.read_xyz('test.xyz',
'~/xyz')

relax> structure.read_xyz(file='test.xyz',
dir='xyz')
```

To load the 10<sup>th</sup> model from the file 'test.xyz' and naming it 'CaM', use one of:

```
relax> structure.read_xyz('test.xyz',
read_model=10, set_mol_name='CaM')

relax> structure.read_xyz(file='test.xyz',
read_model=10, set_mol_name='CaM')
```

To load models 1 and 5 from the file 'test.xyz' as two different structures of the same model, type one of:

```
relax> structure.read_xyz('test.xyz',
read_model=[1, 5], set_model_num=[1, 1])

relax> structure.read_xyz('test.xyz',
set_mol_name=['CaM_1', 'CaM_2'], read_model=
[1, 5], set_model_num=[1, 1])
```

To load the files 'test\_1.xyz', 'test\_2.xyz', 'test\_3.xyz' and 'test\_4.xyz' as models, type the following sequence of commands:

```
relax> structure.read_xyz('test_1.xyz',
set_mol_name='test_1', set_model_num=1)

relax> structure.read_xyz('test_2.xyz',
set_mol_name='test_2', set_model_num=2)

relax> structure.read_xyz('test_3.xyz',
set_mol_name='test_3', set_model_num=3)

relax> structure.read_xyz('test_4.xyz',
set_mol_name='test_4', set_model_num=4)
```

---

**10.2.180 structure.rotate()****Synopsis**

Rotate the internal structural object about the given origin by the rotation matrix.

**Defaults**

**structure.rotate**(self, R=None, origin=None, model=None, atom\_id=None)

**Keyword Arguments**

**R**: The rotation matrix in forwards rotation notation.

**origin**: The origin or pivot of the rotation.

**model**: The model to rotate (which if not set will cause all models to be rotated).

**Description**

This is used to rotate the internal structural data by the given rotation matrix. If the origin is supplied, then this will act as the pivot of the rotation. Otherwise, all structural data will be rotated about the point [0, 0, 0]. The model argument can be used to rotate specific models.

---

**10.2.181 structure.superimpose()****Synopsis**

Superimpose a set of models of the same structure.

**Defaults**

**structure.superimpose**(self, models=None, method='fit to mean', atom\_id=None)

**Keyword Arguments**

**models**: The list of models to superimpose.

**method**: The superimposition method.

**atom\_id**: The atom identification string.

**Description**

This allows a set of models of the same structure to be superimposed to each other. Two superimposition methods are currently supported:

**'fit to mean'** – All models are fit to the mean structure. This is the default and most accurate

**'fit to first'** – This is quicker but is not as accurate for an ensemble description. The Kabsch

If the list of models is not supplied, then all models will be superimposed.

The atom ID, which uses the same notation as the spin ID strings, can be used to restrict the superimpose calculation to certain molecules, residues, or atoms. For example to only superimpose backbone heavy atoms in a protein, use the atom ID of '@N,C,CA,O', assuming those are the names of the atoms from the structural file.

**Examples**

To superimpose all sets of models, type one of:

```
relax> structure.superimpose()
```

```
relax> structure.superimpose(method='fit to mean')
```

To superimpose the models 1, 2, 3, 5 onto model 4, type:

```
relax> structure.superimpose(models=[4, 1, 2, 3, 5], method='fit to first')
```

To superimpose an ensemble of protein structures using only the backbone heavy atoms, type one of:

```
relax> structure.superimpose(atom_id='@N,C,CA,O')
```

```
relax> structure.superimpose(method='fit to mean', atom_id='@N,C,CA,O')
```

To superimpose model 2 onto model 3 using backbone heavy atoms, type one of:

```
relax> structure.superimpose([3, 2], 'fit to first', '@N,C,CA,O')
```

```
relax> structure.superimpose(models=[3, 2], method='fit to first', atom_id='@N,C,CA,O')
```

---

**10.2.182 structure.translate()****Synopsis**

Laterally displace the internal structural object by the translation vector.

## Defaults

**structure.translate**(self, T=None, model=None, atom\_id=None)

## Keyword Arguments

**T**: The translation vector.

**model**: The model to translate (which if not set will cause all models to be translate).

**atom\_id**: The atom identification string.

## Description

This is used to translate the internal structural data by the given translation vector. The model argument can be used to translate specific models.

## Description

For a number of types of analysis, bond vectors or unit bond vectors are required for the calculations. This user function allows these vectors to be extracted from the loaded structures. The bond vector will be that from the atom associated with the spin system loaded in relax to the bonded atom specified by the 'attached' argument. For example if the attached atom is set to 'H' and the protein backbone amide spins 'N' are loaded, the all 'N-H' vectors will be extracted. But if set to 'CA', all atoms named 'CA' in the structures will be searched for and all 'N-Ca' bond vectors will be extracted.

The extraction of vectors can occur in a number of ways. For example if an NMR structure with N models is loaded or if multiple molecules, from any source, of the same compound are loaded as different models, there are three options for extracting the bond vector. Firstly the bond vector of a single model can be extracted by setting the model number. Secondly the bond vectors from all models can be extracted if the model number is not set and the average vector flag is not set. Thirdly, if the model number is not set and the average vector flag is set, then a single vector which is the average for all models will be calculated.

### 10.2.183 structure.vectors()

## Synopsis

Extract and store the bond vectors from the loaded structures in the spin container.

## Defaults

**structure.vectors**(self, attached='H', spin\_id=None, model=None, verbosity=1, ave=True, unit=True)

## Keyword Arguments

**attached**: The name of the second atom which attached to the spin of interest. Regular expression is allowed, for example 'H\*'.  
**spin\_id**: The spin identification string.

**model**: The model to extract bond vectors from (which if not set will cause the vectors of all models to be extracted).

**verbosity**: The amount of information to print to screen. Zero corresponds to minimal output while higher values increase the amount of output. The default value is 1.

**ave**: A flag which if True will cause the bond vectors from all models to be averaged. If vectors from only one model is extracted, this argument will have no effect.

**unit**: A flag which if True will cause the unit vector to be calculated rather than the full length bond vector.

## Examples

To extract the XH vectors of the backbone amide nitrogens where in the PDB file the backbone nitrogen is called 'N' and the attached atom is called 'H', assuming multiple types of spin have already been loaded, type one of:

```
relax> structure.vectors(spin_id='@N')
```

```
relax> structure.vectors('H', spin_id='@N')
```

```
relax> structure.vectors(attached='H', spin_id='@N')
```

If the attached atom is called 'HN', type:

```
relax> structure.vectors(attached='HN', spin_id='@N')
```

For the 'CA' spin bonded to the 'HA' proton, type:

```
relax> structure.vectors(attached='HA', spin_id='@CA')
```

If you are working with RNA, you can use the residue name identifier to calculate the vectors for each residue separately. For example to calculate the vectors for all possible spins in the bases, type:

```
relax> structure.vectors('H2', spin_id=':A')
```

```
relax> structure.vectors('H8', spin_id=':A')
```

```
relax> structure.vectors('H1', spin_id=':G')
```

```
relax> structure.vectors('H8', spin_id=':G')
```

```
relax> structure.vectors('H5', spin_id=':C')
```

```
relax> structure.vectors('H6', spin_id=':C')
```

```
relax> structure.vectors('H3', spin_id=':U')
```

```
relax> structure.vectors('H5', spin_id=':U')
```

```
relax> structure.vectors('H6', spin_id=':U')
```

Alternatively, assuming the desired spins have been loaded, regular expression can be used:

```
relax> structure.vectors('H*')
```

---

### 10.2.184 structure.write\_pdb()

#### Synopsis

Writing structures to a PDB file.

#### Defaults

```
structure.write_pdb(self, file=None, dir=None,
model_num=None, compress_type=0, force=False)
```

#### Keyword Arguments

**file:** The name of the PDB file.

**dir:** The directory where the file is located.

**model\_num:** Restrict the writing of structural data to a single model in the PDB file.

**compress\_type:** The type of compression to use when creating the file.

**force:** A flag which if set to True will cause any pre-existing files to be overwritten.

#### Description

This will write all of the structural data loaded in the current data pipe to be converted to the PDB format and written to file. Specifying the model number allows single models to be output.

The default behaviour of this function is to not compress the file. The compression can, however, be changed to either bzip2 or gzip compression. If the `‘.bz2’` or `‘.gz’` extension is not included in the file name, it will be added. This behaviour is controlled by the `compress_type` argument which can be set to

**0** – No compression (no file extension).

**1** – bzip2 compression (`‘.bz2’` file extension).

**2** – gzip compression (`‘.gz’` file extension).

#### Examples

To write all models and molecules to the PDB file `‘ensemble.pdb’` within the directory `‘~/pdb’`, type one of:

```
relax> structure.write_pdb('ensemble.pdb',
'~/pdb')
```

```
relax> structure.write_pdb(file='ensemble.
pdb', dir='pdb')
```

To write model number 3 into the new file `‘test.pdb’`, use one of:

```
relax> structure.write_pdb('test.pdb',
model_num=3)
```

```
relax> structure.write_pdb(file='test.pdb',
model_num=3)
```

---

### 10.2.185 sys.info()

#### Synopsis

Display all system information relating to this version of relax.

#### Defaults

```
sys.info(self)
```

#### Description

This will display all of the relax, Python, python package and hardware information currently being used by relax. This is useful for seeing if all packages are up to date and if the correct software versions are being used. It is also very useful information for reporting relax bugs.

---

### 10.2.186 system()

#### Synopsis

Function which executes the user supplied shell command.

#### Defaults

```
system(command)
```

---

### 10.2.187 temperature()

#### Synopsis

Specify the temperature of an experiment.

#### Defaults

`temperature(self, id=None, temp=None)`

#### Keyword arguments

`id`: The experiment identification string.

`temp`: The temperature of the experiment.

#### Description

This function allows the temperature of an experiment to be set. In certain analyses, for example those which use pseudocontact shift data, knowledge of the temperature is essential.

---

### 10.2.188 value.copy()

#### Synopsis

Copy spin specific data values from one data pipe to another.

#### Defaults

`value.copy(self, pipe_from=None, pipe_to=None, param=None)`

#### Keyword Arguments

`pipe_from`: The name of the pipe to copy from.

`pipe_to`: The name of the pipe to copy to.

`param`: The parameter to copy. Only one parameter may be selected.

#### Description

If this is used to change values of previously minimised parameters, then the minimisation statistics (chi-squared value, iteration count, function count, gradient count, and Hessian count) will be reset.

#### Examples

To copy the CSA values from the data pipe 'm1' to 'm2', type:

```
relax> value.copy('m1', 'm2', 'CSA')
```

#### Regular expression

The python function 'match', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'[]' – A sequence or set of characters to match to a single character. For example, '[sS]2'

WILL match both 'S2' and 's2'.

'^' – Match the start of the string.

'\$' – Match the end of the string. For example, '^[Ss]2\$' will match 's2' but not 'S2f' or

's2s'.

'.' – Match any character.

'x\*' – Match the character 'x' any number of times, for example 'x' will match, as will 'xxxxx'.

'.\*' – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

#### Model-free set details

Setting a parameter value may have no effect depending on which model-free model is chosen, for example if  $S_f^2$  values and  $S_s^2$  values are set but the run corresponds to model-free model 'm4' then, because these data values are not parameters of the model, they will have no effect.

Note that the  $R_{ex}$  values are scaled quadratically with field strength and should be supplied as a field strength independent value. Use the following formula to get the correct value:

$$\text{value} = R_{ex} / (2.0 * \pi * \text{frequency}) ** 2$$



where:

$R_{ex}$  is the chemical exchange value for the current frequency.

$\pi$  is in the namespace of relax, ie just type 'pi'.

frequency is the proton frequency corresponding to the data.

## N-state model data type string matching patterns

(see table 10.38)

The objects corresponding to the object names are lists (or arrays) with each element corresponding to each state.

## Model-free data type string matching patterns

(see table 10.35)

## Reduced spectral density mapping set details

In reduced spectral density mapping, three values must be set prior to the calculation of spectral density values: the bond length, CSA, and heteronucleus type.

## Reduced spectral density mapping data type string matching patterns

(see table 10.36)

## Relaxation curve fitting set details

Only three parameters can be set, the relaxation rate (Rx), the initial intensity (I0), and the intensity at infinity (Iinf). Setting the parameter Iinf has no effect if the chosen model is that of the exponential curve which decays to zero.

## Relaxation curve fitting data type string matching patterns

(see table 10.37)

## N-state model set details

Setting parameters for the N-state model is a little different from the other type of analyses as each state has a set of parameters with the same names as the other states. To set the parameters for a specific state c (ranging from 0 for the first to N-1 for the last, the number c should be added to the end of the parameter name. So the Euler angle  $\gamma$  of the third state is specified using the string 'gamma2'.

---

## 10.2.189 value.display()

### Synopsis

Display spin specific data values.

### Defaults

`value.display(self, param=None)`

### Keyword Arguments

**param:** The parameter to display. Only one parameter may be selected.

### Examples

To show all CSA values, type:

```
relax> value.display('CSA')
```

### Regular expression

The python function 'match', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'[]' – A sequence or set of characters to match to a single character. For example, '[sS]2'

WILL match both 'S2' and 's2'.

'^' – Match the start of the string.

'\$' – Match the end of the string. For example, '^ [sS] 2\$' will match 's2' but not 'S2f' or



Table 10.35: First table for the value.copy() user function.

| Data type                 | Object name      | Patterns                                     |
|---------------------------|------------------|----------------------------------------------|
| Local $\tau_m$            | 'local_tm'       | '[Ll]ocal[ -_]tm'                            |
| Order parameter $S^2$     | 's2'             | '^[Ss]2\$'                                   |
| Order parameter $S_f^2$   | 's2f'            | '^[Ss]2f\$'                                  |
| Order parameter $S_s^2$   | 's2s'            | '^[Ss]2s\$'                                  |
| Correlation time $\tau_e$ | 'te'             | '^te\$'                                      |
| Correlation time $\tau_f$ | 'tf'             | '^tf\$'                                      |
| Correlation time $\tau_s$ | 'ts'             | '^ts\$'                                      |
| Chemical exchange         | 'rex'            | '^[Rr]ex\$' or '[Cc]emical[ -_] [Ee]xchange' |
| Bond length               | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength'           |
| CSA                       | 'csa'            | '^[Cc] [Ss] [Aa]\$'                          |
| Heteronucleus type        | 'heteronuc_type' | '^[Hh]eteronucleus\$'                        |
| Proton type               | 'proton_type'    | '^[Pp]roton\$'                               |

Table 10.36: Second table for the value.copy() user function.

| Data type          | Object name      | Patterns                           |
|--------------------|------------------|------------------------------------|
| $J(0)$             | 'j0'             | '^[Jj]0\$' or '[Jj]\(0\)'          |
| $J(\omega_X)$      | 'jwx'            | '^[Jj]w[Xx]\$' or '[Jj]\(w[Xx]\)'  |
| $J(\omega_H)$      | 'jwh'            | '^[Jj]w[Hh]\$' or '[Jj]\(w[Hh]\)'  |
| Bond length        | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength' |
| CSA                | 'csa'            | '^[Cc] [Ss] [Aa]\$'                |
| Heteronucleus type | 'heteronuc_type' | '^[Hh]eteronucleus\$'              |
| Proton type        | 'proton_type'    | '^[Pp]roton\$'                     |

Table 10.37: Third table for the value.copy() user function.

| Data type                        | Object name   | Patterns                    |
|----------------------------------|---------------|-----------------------------|
| Relaxation rate                  | 'rx'          | '^[Rr]x\$'                  |
| Peak intensities (series)        | 'intensities' | '^[Ii]nt\$'                 |
| Initial intensity                | 'i0'          | '^[Ii]0\$'                  |
| Intensity at infinity            | 'iinf'        | '^[Ii]inf\$'                |
| Relaxation period times (series) | 'relax_times' | '^[Rr]elax[ -_] [Tt]imes\$' |

Table 10.38: Fourth table for the `value.copy()` user function.

| Data type            | Object name                   | Patterns                                      |
|----------------------|-------------------------------|-----------------------------------------------|
| Probabilities        | <code>'probs'</code>          | <code>'p0', 'p1', 'p2', ..., 'pN'</code>      |
| Euler angle $\alpha$ | <code>'alpha'</code>          | <code>'alpha0', 'alpha1', ...</code>          |
| Euler angle $\beta$  | <code>'beta'</code>           | <code>'beta0', 'beta1', ...</code>            |
| Euler angle $\gamma$ | <code>'gamma'</code>          | <code>'gamma0', 'gamma1', ...</code>          |
| Bond length          | <code>'r'</code>              | <code>'~r\$' or '[Bb]ond[ -][Ll]ength'</code> |
| Heteronucleus type   | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>            |
| Proton type          | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                   |

`'s2s'`.

`'.'` — Match any character.

`'x*'` — Match the character `'x'` any number of times, for example `'x'` will match, as will `'xxxxx'`.

`'.*'` — Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Model-free data type string matching patterns

(see table 10.39)

## Reduced spectral density mapping data type string matching patterns

(see table 10.40)

## NOE calculation data type string matching patterns

(see table 10.41)

## Relaxation curve fitting data type string matching patterns

(see table 10.42)

## N-state model data type string matching patterns

(see table 10.43)

The objects corresponding to the object names are lists (or arrays) with each element corresponding to each state.

## 10.2.190 value.read()

### Synopsis

Read spin specific data values from a file.

### Defaults

`value.read(self, param=None, scaling=1.0, file=None, dir=None, spin_id_col=None, mol_name_col=None, res_num_col=None, res_name_col=None, spin_num_col=None, spin_name_col=None, data_col=None, error_col=None, sep=None, spin_id=None)`

### Keyword Arguments

`param`: The parameter. Only one parameter may be selected.

`scaling`: The factor to scale parameters by.

`file`: The name of the file containing the values.

`dir`: The directory where the file is located.

`spin_id_col`: The spin ID string column (an alternative to the `mol`, `res`, and `spin name` and number columns).

`mol_name_col`: The molecule name column (alternative to the `spin_id_col`).

Table 10.39: First table for the value.display() user function.

| Data type                 | Object name      | Patterns                                     |
|---------------------------|------------------|----------------------------------------------|
| Local $\tau_m$            | 'local_tm'       | '[Ll]ocal[ -_]tm'                            |
| Order parameter $S^2$     | 's2'             | '^[Ss]2\$'                                   |
| Order parameter $S_f^2$   | 's2f'            | '^[Ss]2f\$'                                  |
| Order parameter $S_s^2$   | 's2s'            | '^[Ss]2s\$'                                  |
| Correlation time $\tau_e$ | 'te'             | '^te\$'                                      |
| Correlation time $\tau_f$ | 'tf'             | '^tf\$'                                      |
| Correlation time $\tau_s$ | 'ts'             | '^ts\$'                                      |
| Chemical exchange         | 'rex'            | '^[Rr]ex\$' or '[Cc]emical[ -_] [Ee]xchange' |
| Bond length               | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength'           |
| CSA                       | 'csa'            | '^[Cc] [Ss] [Aa]\$'                          |
| Heteronucleus type        | 'heteronuc_type' | '^[Hh]eteronucleus\$'                        |
| Proton type               | 'proton_type'    | '^[Pp]roton\$'                               |

Table 10.40: Second table for the value.display() user function.

| Data type          | Object name      | Patterns                           |
|--------------------|------------------|------------------------------------|
| $J(0)$             | 'j0'             | '^[Jj]0\$' or '[Jj]\(0\)'          |
| $J(\omega_X)$      | 'jwx'            | '^[Jj]w[Xx]\$' or '[Jj]\(w[Xx]\)'  |
| $J(\omega_H)$      | 'jwh'            | '^[Jj]w[Hh]\$' or '[Jj]\(w[Hh]\)'  |
| Bond length        | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength' |
| CSA                | 'csa'            | '^[Cc] [Ss] [Aa]\$'                |
| Heteronucleus type | 'heteronuc_type' | '^[Hh]eteronucleus\$'              |
| Proton type        | 'proton_type'    | '^[Pp]roton\$'                     |

Table 10.41: Third table for the value.display() user function.

| Data type           | Object name | Patterns                            |
|---------------------|-------------|-------------------------------------|
| Reference intensity | 'ref'       | '^[Rr]ef\$' or '[Rr]ef[ -_] [Ii]nt' |
| Saturated intensity | 'sat'       | '^[Ss]at\$' or '[Ss]at[ -_] [Ii]nt' |
| NOE                 | 'noe'       | '^[Nn] [Oo] [Ee]\$'                 |

Table 10.42: Fourth table for the `value.display()` user function.

| Data type                        | Object name                | Patterns                                |
|----------------------------------|----------------------------|-----------------------------------------|
| Relaxation rate                  | <code>'rx'</code>          | <code>'^[Rr]x\$'</code>                 |
| Peak intensities (series)        | <code>'intensities'</code> | <code>'^[Ii]nt\$'</code>                |
| Initial intensity                | <code>'i0'</code>          | <code>'^[Ii]0\$'</code>                 |
| Intensity at infinity            | <code>'iinf'</code>        | <code>'^[Ii]inf\$'</code>               |
| Relaxation period times (series) | <code>'relax_times'</code> | <code>'^[Rr]elax[ -_][Tt]imes\$'</code> |

Table 10.43: Fifth table for the `value.display()` user function.

| Data type            | Object name                   | Patterns                                       |
|----------------------|-------------------------------|------------------------------------------------|
| Probabilities        | <code>'probs'</code>          | <code>'p0', 'p1', 'p2', ..., 'pN'</code>       |
| Euler angle $\alpha$ | <code>'alpha'</code>          | <code>'alpha0', 'alpha1', ...</code>           |
| Euler angle $\beta$  | <code>'beta'</code>           | <code>'beta0', 'beta1', ...</code>             |
| Euler angle $\gamma$ | <code>'gamma'</code>          | <code>'gamma0', 'gamma1', ...</code>           |
| Bond length          | <code>'r'</code>              | <code>'^r\$' or '[Bb]ond[ -_][Ll]ength'</code> |
| Heteronucleus type   | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>             |
| Proton type          | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                    |

**res\_num\_col**: The residue number column (alternative to the **spin\_id\_col**).

**res\_name\_col**: The residue name column (alternative to the **spin\_id\_col**).

**spin\_num\_col**: The spin number column (alternative to the **spin\_id\_col**).

**spin\_name\_col**: The spin name column (alternative to the **spin\_id\_col**).

**data\_col**: The RDC data column.

**error\_col**: The experimental error column.

**sep**: The column separator (the default is white space).

**spin\_id**: The spin ID string to restrict the loading of data to certain spin subsets.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

**'[]'** – A sequence or set of characters to match to a single character. For example, **'[sS]2'**

**WILL** match both **'S2'** and **'s2'**.

**'^'** – Match the start of the string.

**'\$'** – Match the end of the string. For example, **'^[sS]2\$'** will match **'s2'** but not **'S2f'** or

**'s2s'**.

**'.'** – Match any character.

**'x\*'** – Match the character **'x'** any number of times, for example **'x'** will match, as will **'xxxxx'**.

**'.\*'** – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Description

The spin system can be identified in the file using two different formats. The first is the spin ID string column which can include the molecule name, the residue name and number, and the spin name and number. Alternatively the molecule name, residue number, residue name, spin number and/or spin name columns can be supplied allowing this information to be in separate columns. Note that the numbering of columns starts at one. The spin ID string can be used to restrict the reading to certain spin types, for example only  $^{15}\text{N}$  spins when only residue information is in the file.

If this is used to change values of previously minimised parameters, then the minimisation statistics (chi-squared value, iteration count, function count, gradient count, and Hessian count) will be reset.

## Examples

To load  $^{15}\text{N}$  CSA values from the file **'csa\_values'** in the directory **'data'**, where spins are only identified by residue name and number, type one of the following:

```
relax> value.read('CSA', 'data/csa_value',
spin_id='@N')
```

```
relax> value.read('CSA', 'csa_value', dir=
'data', spin_id='@N')
```

```
relax> value.read(param='CSA', file=
'csa_value', dir='data', res_num_col=1,
res_name_col=2, data_col=3, error_col=4,
spin_id='@N')
```

## Regular expression

The python function **'match'**, which uses regular expression, is used to determine which data type to set values to, therefore various **data\_type** strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

## Model-free set details

Setting a parameter value may have no effect depending on which model-free model is chosen, for example if  $S_f^2$  values and  $S_s^2$  values are set but the run corresponds to model-free model **'m4'** then, because these data values are not parameters of the model, they will have no effect.

Note that the  $R_{ex}$  values are scaled quadratically with field strength and should be supplied as a field strength independent value. Use the following formula to get the correct value:

$$\text{value} = R_{ex} / (2.0 * \pi * \text{frequency}) ** 2$$

where:

$R_{ex}$  is the chemical exchange value for the current frequency.

$\pi$  is in the namespace of relax, ie just type **'pi'**.

frequency is the proton frequency corresponding to the data.

Table 10.44: First table for the `value.read()` user function.

| Data type                 | Object name                   | Patterns                                                 |
|---------------------------|-------------------------------|----------------------------------------------------------|
| Local $\tau_m$            | <code>'local_tm'</code>       | <code>'^[Ll]ocal[ -_]tm'</code>                          |
| Order parameter $S^2$     | <code>'s2'</code>             | <code>'^[Ss]2\$'</code>                                  |
| Order parameter $S_f^2$   | <code>'s2f'</code>            | <code>'^[Ss]2f\$'</code>                                 |
| Order parameter $S_s^2$   | <code>'s2s'</code>            | <code>'^[Ss]2s\$'</code>                                 |
| Correlation time $\tau_e$ | <code>'te'</code>             | <code>'^te\$'</code>                                     |
| Correlation time $\tau_f$ | <code>'tf'</code>             | <code>'^tf\$'</code>                                     |
| Correlation time $\tau_s$ | <code>'ts'</code>             | <code>'^ts\$'</code>                                     |
| Chemical exchange         | <code>'rex'</code>            | <code>'^[Rr]ex\$' or '[Cc]emical[ -_][Ee]xchange'</code> |
| Bond length               | <code>'r'</code>              | <code>'^r\$' or '[Bb]ond[ -_][Ll]ength'</code>           |
| CSA                       | <code>'csa'</code>            | <code>'^[Cc][Ss][Aa]\$'</code>                           |
| Heteronucleus type        | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                       |
| Proton type               | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                              |

### Model-free data type string matching patterns

(see table 10.44)

### Relaxation curve fitting data type string matching patterns

(see table 10.46)

### Reduced spectral density mapping set details

In reduced spectral density mapping, three values must be set prior to the calculation of spectral density values: the bond length, CSA, and heteronucleus type.

### Reduced spectral density mapping data type string matching patterns

(see table 10.45)

### N-state model set details

Setting parameters for the N-state model is a little different from the other type of analyses as each state has a set of parameters with the same names as the other states. To set the parameters for a specific state *c* (ranging from 0 for the first to N-1 for the last, the number *c* should be added to the end of the parameter name. So the Euler angle  $\gamma$  of the third state is specified using the string `'gamma2'`.

### N-state model data type string matching patterns

(see table 10.47)

### Relaxation curve fitting set details

Only three parameters can be set, the relaxation rate (Rx), the initial intensity (I0), and the intensity at infinity (Iinf). Setting the parameter Iinf has no effect if the chosen model is that of the exponential curve which decays to zero.

The objects corresponding to the object names are lists (or arrays) with each element corresponding to each state.

Table 10.45: Second table for the value.read() user function.

| Data type          | Object name      | Patterns                           |
|--------------------|------------------|------------------------------------|
| $J(0)$             | 'j0'             | '^[Jj]0\$' or '[Jj]\(0\).'         |
| $J(\omega_X)$      | 'jwx'            | '^[Jj]w[Xx]\$' or '[Jj]\(w[Xx]\).' |
| $J(\omega_H)$      | 'jwh'            | '^[Jj]w[Hh]\$' or '[Jj]\(w[Hh]\).' |
| Bond length        | 'r'              | '^r\$' or '[Bb]ond[ -_][Ll]ength'  |
| CSA                | 'csa'            | '^[Cc][Ss][Aa]\$'                  |
| Heteronucleus type | 'heteronuc_type' | '^[Hh]eteronucleus\$'              |
| Proton type        | 'proton_type'    | '^[Pp]roton\$'                     |

Table 10.46: Third table for the value.read() user function.

| Data type                        | Object name   | Patterns                   |
|----------------------------------|---------------|----------------------------|
| Relaxation rate                  | 'rx'          | '^[Rr]x\$'                 |
| Peak intensities (series)        | 'intensities' | '^[Ii]nt\$'                |
| Initial intensity                | 'i0'          | '^[Ii]0\$'                 |
| Intensity at infinity            | 'iinf'        | '^[Ii]inf\$'               |
| Relaxation period times (series) | 'relax_times' | '^[Rr]elax[ -_][Tt]imes\$' |

Table 10.47: Fourth table for the value.read() user function.

| Data type            | Object name      | Patterns                          |
|----------------------|------------------|-----------------------------------|
| Probabilities        | 'probs'          | 'p0', 'p1', 'p2', ..., 'pN'       |
| Euler angle $\alpha$ | 'alpha'          | 'alpha0', 'alpha1', ...           |
| Euler angle $\beta$  | 'beta'           | 'beta0', 'beta1', ...             |
| Euler angle $\gamma$ | 'gamma'          | 'gamma0', 'gamma1', ...           |
| Bond length          | 'r'              | '^r\$' or '[Bb]ond[ -_][Ll]ength' |
| Heteronucleus type   | 'heteronuc_type' | '^[Hh]eteronucleus\$'             |
| Proton type          | 'proton_type'    | '^[Pp]roton\$'                    |

### 10.2.191 value.set()

#### Synopsis

Set spin specific data values.

#### Defaults

`value.set(self, val=None, param=None, spin_id=None)`

#### Keyword Arguments

`val`: The value(s).

`param`: The parameter(s).

`spin_id`: The spin identifier.

#### Description

If this function is used to change values of previously minimised results, then the minimisation statistics (chi-squared value, iteration count, function count, gradient count, and Hessian count) will be reset to None.

The `val` argument can be None, a single value, or an array of values while the parameter argument can be None, a string, or array of strings. The choice of which combination determines the behaviour of this function. The following table describes what occurs in each instance. The Value column refers to the '`val`' argument while the Param column refers to the '`param`' argument. In these columns, '`None`' corresponds to None, '`1`' corresponds to either a single value or single string, and '`n`' corresponds to either an array of values or an array of strings.

(see table 10.48)

#### Examples

To set the parameter values for the current data pipe to the default values, for all spins, type:

```
relax> value.set()
```

To set the parameter values of residue 10, which is in the current model-free data pipe 'm4' and has the parameters  $\{S^2, \tau_e, R_{ex}\}$ , the following can be used.  $R_{ex}$  term is the value for the first given field strength.

```
relax> value.set([0.97, 2.048*1e-9, 0.149],
spin_id='10')
```

```
relax> value.set(val=[0.97, 2.048*1e-9,
0.149], spin_id='10')
```

To set the CSA value of all spins to the default value, type:

```
relax> value.set(param='csa')
```

To set the CSA value of all spins to -172 ppm, type:

```
relax> value.set(-172 * 1e-6, 'csa')
```

```
relax> value.set(val=-172 * 1e-6, param=
'csa')
```

To set the NH bond length of all spins to 1.02 Å, type:

```
relax> value.set(1.02 * 1e-10,
'bond_length')
```

```
relax> value.set(val=1.02 * 1e-10, param=
'r')
```

To set both the bond length and the CSA value to the default values, type:

```
relax> value.set(param=['bond length',
'csa'])
```

To set both  $\tau_f$  and  $\tau_s$  to 100 ps, type:

```
relax> value.set(100e-12, ['tf', 'ts'])
```

```
relax> value.set(val=100e-12, param=['tf',
'ts'])
```

To set the  $S^2$  and  $\tau_e$  parameter values of residue 126, Ca spins to 0.56 and 13 ps, type:

```
relax> value.set([0.56, 13e-12], ['S2',
'te'], ':126@Ca')
```

```
relax> value.set(val=[0.56, 13e-12], param=
['S2', 'te'], spin_id=':126@Ca')
```

```
relax> value.set(val=[0.56, 13e-12], param=
['S2', 'te'], spin_id=':126@Ca')
```

#### Spin identification

If the spin ID is left unset, then this will be applied to all spins. If the data is global non-spin specific data, such as diffusion tensor parameters, supplying the spin identifier will terminate the program with an error.

#### Regular expression

The python function '`match`', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

'`[]`' – A sequence or set of characters to match to a single character. For example, '`[sS]2`'

WILL match both '`S2`' and '`s2`'.

'`^`' – Match the start of the string.

'`$`' – Match the end of the string. For example, '`^[sS]2$`' will match '`s2`' but not '`S2f`' or



Table 10.48: First table for the `value.set()` user function.

| Value | Param | Description                                                                                                                                                                                                              |
|-------|-------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| None  | None  | This case is used to set the model parameters prior to minimisation or calculation. The model parameters are set to the default values.                                                                                  |
| 1     | None  | Invalid combination.                                                                                                                                                                                                     |
| $n$   | None  | This case is used to set the model parameters prior to minimisation or calculation. The length of the val array must be equal to the number of model parameters. The parameters will be set to the corresponding number. |
| None  | 1     | The parameter matching the string will be set to the default value.                                                                                                                                                      |
| 1     | 1     | The parameter matching the string will be set to the supplied number.                                                                                                                                                    |
| $n$   | 1     | Invalid combination.                                                                                                                                                                                                     |
| None  | $n$   | Each parameter matching the strings will be set to the default values.                                                                                                                                                   |
| 1     | $n$   | Each parameter matching the strings will be set to the supplied number.                                                                                                                                                  |
| $n$   | $n$   | Each parameter matching the strings will be set to the corresponding number. Both arrays must be of equal length.                                                                                                        |

‘s2s’.

$R_{ex}$  is the chemical exchange value for the current frequency.

‘.’ – Match any character.

$\pi$  is in the namespace of relax, ie just type ‘pi’.

‘x\*’ – Match the character ‘x’ any number of times, for example ‘x’ will match, as will ‘xxxx’.

frequency is the proton frequency corresponding to the data.

‘.\*’ – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Model-free data type string matching patterns

(see table 10.49)

## Model-free set details

Setting a parameter value may have no effect depending on which model-free model is chosen, for example if  $S_f^2$  values and  $S_s^2$  values are set but the run corresponds to model-free model ‘m4’ then, because these data values are not parameters of the model, they will have no effect.

Note that the  $R_{ex}$  values are scaled quadratically with field strength and should be supplied as a field strength independent value. Use the following formula to get the correct value:

$$\text{value} = R_{ex} / (2.0 * \pi * \text{frequency}) ** 2$$

where:

## Model-free default values

(see table 10.50)

## Reduced spectral density mapping set details

In reduced spectral density mapping, three values must be set prior to the calculation of spectral density values: the bond length, CSA, and heteronucleus type.

## Reduced spectral density mapping data type string matching patterns

(see table 10.51)

Table 10.49: Second table for the `value.set()` user function.

| Data type                 | Object name                   | Patterns                                                              |
|---------------------------|-------------------------------|-----------------------------------------------------------------------|
| Local $\tau_m$            | <code>'local_tm'</code>       | <code>'[Ll]ocal[ -_]tm'</code>                                        |
| Order parameter $S^2$     | <code>'s2'</code>             | <code>'^[Ss]2\$'</code>                                               |
| Order parameter $S_f^2$   | <code>'s2f'</code>            | <code>'^[Ss]2f\$'</code>                                              |
| Order parameter $S_s^2$   | <code>'s2s'</code>            | <code>'^[Ss]2s\$'</code>                                              |
| Correlation time $\tau_e$ | <code>'te'</code>             | <code>'^te\$'</code>                                                  |
| Correlation time $\tau_f$ | <code>'tf'</code>             | <code>'^tf\$'</code>                                                  |
| Correlation time $\tau_s$ | <code>'ts'</code>             | <code>'^ts\$'</code>                                                  |
| Chemical exchange         | <code>'rex'</code>            | <code>'^[Rr]ex\$'</code> or <code>'[Cc]emical[ -_][Ee]xchange'</code> |
| Bond length               | <code>'r'</code>              | <code>'^r\$'</code> or <code>'[Bb]ond[ -_][Ll]ength'</code>           |
| CSA                       | <code>'csa'</code>            | <code>'^[Cc][Ss][Aa]\$'</code>                                        |
| Heteronucleus type        | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                                    |
| Proton type               | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                                           |

Table 10.50: Third table for the `value.set()` user function.

| Data type                                      | Object name                                                 | Value                     |
|------------------------------------------------|-------------------------------------------------------------|---------------------------|
| Local $\tau_m$                                 | <code>'local_tm'</code>                                     | <code>10 * 1e-9</code>    |
| Order parameters $S^2$ , $S_f^2$ , and $S_s^2$ | <code>'s2'</code> , <code>'s2f'</code> , <code>'s2s'</code> | <code>0.8</code>          |
| Correlation time $\tau_e$                      | <code>'te'</code>                                           | <code>100 * 1e-12</code>  |
| Correlation time $\tau_f$                      | <code>'tf'</code>                                           | <code>10 * 1e-12</code>   |
| Correlation time $\tau_s$                      | <code>'ts'</code>                                           | <code>1000 * 1e-12</code> |
| Chemical exchange relaxation                   | <code>'rex'</code>                                          | <code>0.0</code>          |
| Bond length                                    | <code>'r'</code>                                            | <code>1.02 * 1e-10</code> |
| CSA                                            | <code>'csa'</code>                                          | <code>-172 * 1e-6</code>  |
| Heteronucleus type                             | <code>'heteronuc_type'</code>                               | <code>'15N'</code>        |
| Proton type                                    | <code>'proton_type'</code>                                  | <code>'1H'</code>         |

Table 10.51: Fourth table for the `value.set()` user function.

| Data type          | Object name                   | Patterns                                                     |
|--------------------|-------------------------------|--------------------------------------------------------------|
| $J(0)$             | <code>'j0'</code>             | <code>'^[Jj]0\$'</code> or <code>'[Jj]\(0\).'</code>         |
| $J(\omega_X)$      | <code>'jwx'</code>            | <code>'^[Jj]w[Xx]\$'</code> or <code>'[Jj]\(w[Xx]\).'</code> |
| $J(\omega_H)$      | <code>'jwh'</code>            | <code>'^[Jj]w[Hh]\$'</code> or <code>'[Jj]\(w[Hh]\).'</code> |
| Bond length        | <code>'r'</code>              | <code>'^r\$'</code> or <code>'[Bb]ond[ -_][Ll]ength'</code>  |
| CSA                | <code>'csa'</code>            | <code>'^[Cc][Ss][Aa]\$'</code>                               |
| Heteronucleus type | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>                           |
| Proton type        | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                                  |

### Reduced spectral density mapping default values

These default values are found in the file `'physical_constants.py'`.

(see table 10.52)

$$\{\mathfrak{D}_{iso}, \mathfrak{D}_a\},$$

$$\{\tau_m, \mathfrak{D}_{ratio}\},$$

$$\{\mathfrak{D}_{\parallel}, \mathfrak{D}_{\perp}\},$$

$$\{\mathfrak{D}_{iso}, \mathfrak{D}_{ratio}\},$$

### Diffusion tensor set details

If the diffusion tensor has not been setup, use the more powerful function `'diffusion_tensor.init'` to initialise the tensor parameters. This function cannot be used to initialise a diffusion tensor.

The units of the parameters are:

Inverse seconds for  $\tau_m$ .

Seconds for  $\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_x, \mathfrak{D}_y, \mathfrak{D}_z, \mathfrak{D}_{\parallel}, \mathfrak{D}_{\perp}$ .

Unitless for  $\mathfrak{D}_{ratio}$  and  $\mathfrak{D}_r$ .

Radians for all angles ( $\alpha, \beta, \gamma, \theta, \phi$ ).

where either  $\theta, \phi$ , or both orientational parameters can be additionally supplied. For ellipsoidal diffusion, again when supplying multiple geometric parameters, the set must belong to one of

$$\{\tau_m, \mathfrak{D}_a, \mathfrak{D}_r\},$$

$$\{\mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r\},$$

$$\{\mathfrak{D}_x, \mathfrak{D}_y, \mathfrak{D}_z\},$$

where any number of the orientational parameters,  $\alpha, \beta$ , or  $\gamma$  can be additionally supplied.

### Diffusion tensor parameter string matching patterns

(see table 10.53)

### Diffusion tensor parameter default values

(see table 10.54)

When setting a diffusion tensor parameter, the residue number has no effect. As the internal parameters of spherical diffusion are  $\{\tau_m\}$ , spheroidal diffusion are  $\{\tau_m, \mathfrak{D}_a, \theta, \phi\}$ , and ellipsoidal diffusion are  $\{\tau_m, \mathfrak{D}_a, \mathfrak{D}_r, \alpha, \beta, \gamma\}$ , supplying geometric parameters must be done in the following way. If a single geometric parameter is supplied, it must be one of  $\tau_m, \mathfrak{D}_{iso}, \mathfrak{D}_a, \mathfrak{D}_r$ , or  $\mathfrak{D}_{ratio}$ . For the parameters  $\mathfrak{D}_{\parallel}, \mathfrak{D}_{\perp}, \mathfrak{D}_x, \mathfrak{D}_y$ , and  $\mathfrak{D}_z$ , it is not possible to determine how to use the currently set values together with the supplied value to calculate the new internal parameters. For spheroidal diffusion, when supplying multiple geometric parameters, the set must belong to one of

$$\{\tau_m, \mathfrak{D}_a\},$$

Table 10.52: Fifth table for the `value.set()` user function.

| Data type          | Object name                   | Value              |
|--------------------|-------------------------------|--------------------|
| Bond length        | <code>'r'</code>              | $1.02 * 1e-10$     |
| CSA                | <code>'csa'</code>            | $-172 * 1e-6$      |
| Heteronucleus type | <code>'heteronuc_type'</code> | <code>'15N'</code> |
| Proton type        | <code>'proton_type'</code>    | <code>'1H'</code>  |

Table 10.53: Sixth table for the `value.set()` user function.

| Data type                                                                                                       | Object name           | Patterns                                    |
|-----------------------------------------------------------------------------------------------------------------|-----------------------|---------------------------------------------|
| Global correlation time - $\tau_m$                                                                              | <code>'tm'</code>     | <code>'^tm\$'</code>                        |
| Isotropic component of the diffusion tensor - $\mathfrak{D}_{iso}$                                              | <code>'Diso'</code>   | <code>'[Dd]iso'</code>                      |
| Anisotropic component of the diffusion tensor - $\mathfrak{D}_a$                                                | <code>'Da'</code>     | <code>'[Dd]a'</code>                        |
| Rhombic component of the diffusion tensor - $\mathfrak{D}_r$                                                    | <code>'Dr'</code>     | <code>'[Dd]r\$'</code>                      |
| Eigenvalue associated with the x-axis of the diffusion diffusion tensor - $\mathfrak{D}_x$                      | <code>'Dx'</code>     | <code>'[Dd]x'</code>                        |
| Eigenvalue associated with the y-axis of the diffusion diffusion tensor - $\mathfrak{D}_y$                      | <code>'Dy'</code>     | <code>'[Dd]y'</code>                        |
| Eigenvalue associated with the z-axis of the diffusion diffusion tensor - $\mathfrak{D}_z$                      | <code>'Dz'</code>     | <code>'[Dd]z'</code>                        |
| Diffusion coefficient parallel to the major axis of the spheroid diffusion tensor - $\mathfrak{D}_{  }$         | <code>'Dpar'</code>   | <code>'[Dd]par'</code>                      |
| Diffusion coefficient perpendicular to the major axis of the spheroid diffusion tensor - $\mathfrak{D}_{\perp}$ | <code>'Dper'</code>   | <code>'[Dd]per'</code>                      |
| Ratio of the parallel and perpendicular components of the spheroid diffusion tensor - $\mathfrak{D}_{ratio}$    | <code>'Dratio'</code> | <code>'[Dd]ratio'</code>                    |
| The first Euler angle of the ellipsoid diffusion tensor - $\alpha$                                              | <code>'alpha'</code>  | <code>'^a\$'</code> or <code>'alpha'</code> |
| The second Euler angle of the ellipsoid diffusion tensor - $\beta$                                              | <code>'beta'</code>   | <code>'^b\$'</code> or <code>'beta'</code>  |
| The third Euler angle of the ellipsoid diffusion tensor - $\gamma$                                              | <code>'gamma'</code>  | <code>'^g\$'</code> or <code>'gamma'</code> |
| The polar angle defining the major axis of the spheroid diffusion tensor - $\theta$                             | <code>'theta'</code>  | <code>'theta'</code>                        |
| The azimuthal angle defining the major axis of the spheroid diffusion tensor - $\phi$                           | <code>'phi'</code>    | <code>'phi'</code>                          |

Table 10.54: Seventh table for the `value.set()` user function.

| Data type                  | Object name | Value         |
|----------------------------|-------------|---------------|
| $\tau_m$                   | 'tm'        | $10 * 1e-9$   |
| $\mathfrak{D}_{iso}$       | 'Diso'      | $1.666 * 1e7$ |
| $\mathfrak{D}_a$           | 'Da'        | 0.0           |
| $\mathfrak{D}_r$           | 'Dr'        | 0.0           |
| $\mathfrak{D}_x$           | 'Dx'        | $1.666 * 1e7$ |
| $\mathfrak{D}_y$           | 'Dy'        | $1.666 * 1e7$ |
| $\mathfrak{D}_z$           | 'Dz'        | $1.666 * 1e7$ |
| $\mathfrak{D}_{\parallel}$ | 'Dpar'      | $1.666 * 1e7$ |
| $\mathfrak{D}_{\perp}$     | 'Dper'      | $1.666 * 1e7$ |
| $\mathfrak{D}_{ratio}$     | 'Dratio'    | 1.0           |
| $\alpha$                   | 'alpha'     | 0.0           |
| $\beta$                    | 'beta'      | 0.0           |
| $\gamma$                   | 'gamma'     | 0.0           |
| $\theta$                   | 'theta'     | 0.0           |
| $\phi$                     | 'phi'       | 0.0           |

## Relaxation curve fitting set details

Only three parameters can be set, the relaxation rate ( $R_x$ ), the initial intensity ( $I_0$ ), and the intensity at infinity ( $I_{inf}$ ). Setting the parameter  $I_{inf}$  has no effect if the chosen model is that of the exponential curve which decays to zero.

## Relaxation curve fitting data type string matching patterns

(see table [10.55](#))

## Relaxation curve fitting default values

These values are completely arbitrary as peak heights (or volumes) are extremely variable and the  $R_x$  value is a compensation for both the  $R_1$  and  $R_2$  values.

(see table [10.56](#))

## N-state model set details

Setting parameters for the N-state model is a little different from the other type of analyses as each state has a set of parameters with the same names as the other states. To set the parameters for a specific state  $c$  (ranging from 0 for the first to  $N-1$  for the last, the number  $c$  should be added to the end of the parameter name. So the Euler angle  $\gamma$  of the third state is specified using the string 'gamma2'.

## N-state model data type string matching patterns

(see table [10.57](#))

The objects corresponding to the object names are lists (or arrays) with each element corresponding to each state.

## N-state model default values

(see table [10.58](#))

In this table,  $N$  is the total number of states and  $c$  is the index of a given state ranging from 0 to  $N-1$ . The default probabilities are all set to be equal whereas the angles are given a range of values so that no 2 states are equal at the start of optimisation.

Note that setting the probability for state  $N$  will do nothing as it is equal to one minus all the other probabilities.

## 10.2.192 value.write()

### Synopsis

Write spin specific data values to a file.

### Defaults

**value.write**(self, param=None, file=None, dir=None, bc=False, force=False)

### Keyword Arguments

**param**: The parameter.

**file**: The name of the file.

**dir**: The directory name.

**bc**: A flag which if True will cause the back calculated values to be written to file rather than the actual data.

**force**: A flag which, if set to True, will cause the file to be overwritten.

### Description

The values corresponding to the given parameter will be written to file.

### Examples

To write the CSA values to the file 'csa.txt', type one of:

```
relax> value.write('CSA', 'csa.txt')
```

```
relax> value.write(param='CSA', file='csa.txt')
```

To write the NOE values to the file 'noe', type one of:

```
relax> value.write('noe', 'noe.out')
```

```
relax> value.write(param='noe', file='noe.out')
```

```
relax> value.write(param='noe', file='noe.out')
```

```
relax> value.write(param='noe', file='noe.out', force=True)
```

### Regular expression

The python function 'match', which uses regular expression, is used to determine which data type to set values to, therefore various data\_type strings can be used to select the same data type. Patterns used for matching for specific data types are listed below.

Table 10.55: Eighth table for the `value.set()` user function.

| Data type                        | Object name                | Patterns                                |
|----------------------------------|----------------------------|-----------------------------------------|
| Relaxation rate                  | <code>'rx'</code>          | <code>'^[Rr]x\$'</code>                 |
| Peak intensities (series)        | <code>'intensities'</code> | <code>'^[Ii]nt\$'</code>                |
| Initial intensity                | <code>'i0'</code>          | <code>'^[Ii]0\$'</code>                 |
| Intensity at infinity            | <code>'iinf'</code>        | <code>'^[Ii]inf\$'</code>               |
| Relaxation period times (series) | <code>'relax_times'</code> | <code>'^[Rr]elax[ -_][Tt]imes\$'</code> |

Table 10.56: Ninth table for the `value.set()` user function.

| Data type             | Object name         | Value   |
|-----------------------|---------------------|---------|
| Relaxation rate       | <code>'rx'</code>   | 8.0     |
| Initial intensity     | <code>'i0'</code>   | 10000.0 |
| Intensity at infinity | <code>'iinf'</code> | 0.0     |

Table 10.57: Tenth table for the `value.set()` user function.

| Data type            | Object name                   | Patterns                                       |
|----------------------|-------------------------------|------------------------------------------------|
| Probabilities        | <code>'probs'</code>          | <code>'p0', 'p1', 'p2', ..., 'pN'</code>       |
| Euler angle $\alpha$ | <code>'alpha'</code>          | <code>'alpha0', 'alpha1', ...</code>           |
| Euler angle $\beta$  | <code>'beta'</code>           | <code>'beta0', 'beta1', ...</code>             |
| Euler angle $\gamma$ | <code>'gamma'</code>          | <code>'gamma0', 'gamma1', ...</code>           |
| Bond length          | <code>'r'</code>              | <code>'^r\$' or '[Bb]ond[ -_][Ll]ength'</code> |
| Heteronucleus type   | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>             |
| Proton type          | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                    |

Table 10.58: Eleventh table for the `value.set()` user function.

| Data type            | Object name                              | Value                 |
|----------------------|------------------------------------------|-----------------------|
| Probabilities        | <code>'p0', 'p1', 'p2', ..., 'pN'</code> | $1/N$                 |
| Euler angle $\alpha$ | <code>'alpha0', 'alpha1', ...</code>     | $(c+1) * \pi / (N+1)$ |
| Euler angle $\beta$  | <code>'beta0', 'beta1', ...</code>       | $(c+1) * \pi / (N+1)$ |
| Euler angle $\gamma$ | <code>'gamma0', 'gamma1', ...</code>     | $(c+1) * \pi / (N+1)$ |

This is a short description of python regular expression, for more information see the regular expression syntax section of the Python Library Reference. Some of the regular expression syntax used in this function is:

`[]` – A sequence or set of characters to match to a single character. For example, `[sS]2`

WILL match both `'S2'` and `'s2'`.

`^` – Match the start of the string.

`$` – Match the end of the string. For example, `^[Ss]2$` will match `'s2'` but not `'S2f'` or

`'s2s'`.

`.` – Match any character.

`x*` – Match the character `'x'` any number of times, for example `'x'` will match, as will `'xxxxx'`.

`.*` – Match any sequence of characters of any length.

Importantly, do not supply a string for the data type containing regular expression. The regular expression is implemented so that various strings can be supplied which all match the same data type.

## Model-free data type string matching patterns

(see table [10.59](#))

## Reduced spectral density mapping data type string matching patterns

(see table [10.60](#))

## NOE calculation data type string matching patterns

(see table [10.61](#))

## Relaxation curve fitting data type string matching patterns

(see table [10.62](#))

## N-state model data type string matching patterns

(see table [10.63](#))

The objects corresponding to the object names are lists (or arrays) with each element corresponding to each state.

---

### 10.2.193 vmd.view()

#### Synopsis

Function for viewing the collection of molecules extracted from the PDB file.

#### Defaults

`vmd.view(self)`

#### Example

```
relax> vmd.view()
```



Table 10.59: First table for the value.write() user function.

| Data type                 | Object name      | Patterns                                     |
|---------------------------|------------------|----------------------------------------------|
| Local $\tau_m$            | 'local_tm'       | '[Ll]ocal[ -_]tm'                            |
| Order parameter $S^2$     | 's2'             | '^[Ss]2\$'                                   |
| Order parameter $S_f^2$   | 's2f'            | '^[Ss]2f\$'                                  |
| Order parameter $S_s^2$   | 's2s'            | '^[Ss]2s\$'                                  |
| Correlation time $\tau_e$ | 'te'             | '^te\$'                                      |
| Correlation time $\tau_f$ | 'tf'             | '^tf\$'                                      |
| Correlation time $\tau_s$ | 'ts'             | '^ts\$'                                      |
| Chemical exchange         | 'rex'            | '^[Rr]ex\$' or '[Cc]emical[ -_] [Ee]xchange' |
| Bond length               | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength'           |
| CSA                       | 'csa'            | '^[Cc] [Ss] [Aa]\$'                          |
| Heteronucleus type        | 'heteronuc_type' | '^[Hh]eteronucleus\$'                        |
| Proton type               | 'proton_type'    | '^[Pp]roton\$'                               |

Table 10.60: Second table for the value.write() user function.

| Data type          | Object name      | Patterns                           |
|--------------------|------------------|------------------------------------|
| $J(0)$             | 'j0'             | '^[Jj]0\$' or '[Jj]\(0\)'          |
| $J(\omega_X)$      | 'jwx'            | '^[Jj]w[Xx]\$' or '[Jj]\(w[Xx]\)'  |
| $J(\omega_H)$      | 'jwh'            | '^[Jj]w[Hh]\$' or '[Jj]\(w[Hh]\)'  |
| Bond length        | 'r'              | '^r\$' or '[Bb]ond[ -_] [Ll]ength' |
| CSA                | 'csa'            | '^[Cc] [Ss] [Aa]\$'                |
| Heteronucleus type | 'heteronuc_type' | '^[Hh]eteronucleus\$'              |
| Proton type        | 'proton_type'    | '^[Pp]roton\$'                     |

Table 10.61: Third table for the value.write() user function.

| Data type           | Object name | Patterns                            |
|---------------------|-------------|-------------------------------------|
| Reference intensity | 'ref'       | '^[Rr]ef\$' or '[Rr]ef[ -_] [Ii]nt' |
| Saturated intensity | 'sat'       | '^[Ss]at\$' or '[Ss]at[ -_] [Ii]nt' |
| NOE                 | 'noe'       | '^[Nn] [Oo] [Ee]\$'                 |

Table 10.62: Fourth table for the `value.write()` user function.

| Data type                        | Object name                | Patterns                                |
|----------------------------------|----------------------------|-----------------------------------------|
| Relaxation rate                  | <code>'rx'</code>          | <code>'^[Rr]x\$'</code>                 |
| Peak intensities (series)        | <code>'intensities'</code> | <code>'^[Ii]nt\$'</code>                |
| Initial intensity                | <code>'i0'</code>          | <code>'^[Ii]0\$'</code>                 |
| Intensity at infinity            | <code>'iinf'</code>        | <code>'^[Ii]inf\$'</code>               |
| Relaxation period times (series) | <code>'relax_times'</code> | <code>'^[Rr]elax[ -_][Tt]imes\$'</code> |

Table 10.63: Fifth table for the `value.write()` user function.

| Data type            | Object name                   | Patterns                                       |
|----------------------|-------------------------------|------------------------------------------------|
| Probabilities        | <code>'probs'</code>          | <code>'p0', 'p1', 'p2', ..., 'pN'</code>       |
| Euler angle $\alpha$ | <code>'alpha'</code>          | <code>'alpha0', 'alpha1', ...</code>           |
| Euler angle $\beta$  | <code>'beta'</code>           | <code>'beta0', 'beta1', ...</code>             |
| Euler angle $\gamma$ | <code>'gamma'</code>          | <code>'gamma0', 'gamma1', ...</code>           |
| Bond length          | <code>'r'</code>              | <code>'~r\$' or '[Bb]ond[ -_][Ll]ength'</code> |
| Heteronucleus type   | <code>'heteronuc_type'</code> | <code>'^[Hh]eteronucleus\$'</code>             |
| Proton type          | <code>'proton_type'</code>    | <code>'^[Pp]roton\$'</code>                    |

# Chapter 11

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# Index

- angles, [144](#), [145](#), [146](#), [146](#), [155–157](#), [160](#),  
[162–164](#), [204](#), [205](#), [251](#), [252](#), [260](#),  
[262](#), [264](#), [266](#), [267](#), [271](#), [272](#), [274](#),  
[275](#), [278](#)
- API documentation, [132](#)
- argument, [5](#)
  - keyword, [5](#)
- bond length, [161](#), [167](#), [168](#), [172](#), [175](#), [176](#),  
[260–264](#), [266–272](#), [275](#), [277](#), [278](#)
- branches, [130](#)
- bug, [18](#), [137](#)
  - design, [18](#)
  - search, [19](#)
- bug report, [126](#)
- bug tracker, [13](#), [14](#), [18–20](#), [126](#), [129](#), [133](#)
- C module compilation, [13](#), [132](#)
- camel case, [123](#)
- chemical exchange, [161](#), [168](#), [172](#), [182](#), [186](#),  
[216](#), [221](#), [260](#), [261](#), [263](#), [265](#), [266](#),  
[269](#), [270](#), [277](#)
- chi-squared, [33](#), [38](#), [38–40](#), [44](#), [48](#), [167](#), [199](#),  
[211](#), [228](#)
- chi-squared gradient, [48](#)
- chi-squared Hessian, [48](#)
- clean up, [133](#)
- commit access, [127](#)
- commit log, [127](#), [128](#)
- compression, [236](#), [249](#), [258](#)
  - bzip2, [235](#), [236](#), [249](#), [250](#), [254](#), [258](#)
  - gzip, [235](#), [236](#), [249](#), [254](#), [258](#)
  - uncompressed, [235](#), [249](#), [250](#), [254](#)
- constraint, [156](#), [161](#), [166](#), [169](#), [170](#), [207](#)
- copy, [143](#), [154](#), [176](#), [177](#), [209](#), [212](#), [225](#), [226](#),  
[228](#), [229](#), [232](#), [238](#), [245](#), [259](#)
- correlation time, [155–157](#), [160](#), [161](#), [161](#),  
[168](#), [172](#), [182](#), [186](#), [216](#), [221](#), [251](#),  
[261](#), [263](#), [266](#), [270](#), [272](#), [277](#)
- ctypes, [14](#)
- data pipe, [7](#)
- delete, [143](#), [154](#), [174](#), [178](#), [210](#), [213](#), [226](#), [229](#),  
[233](#), [241](#), [246](#), [252](#)
- diff, [19](#)
- diffusion, [35](#)
  - anisotropic, [156](#), [157](#), [160](#), [272](#)
  - Brownian, [35](#), [197](#), [223](#), [251](#)
  - ellipsoid (asymmetric), [35](#), [48](#), [95](#), [146](#),  
[156](#), [156](#), [157](#), [160](#), [251](#), [271](#), [272](#)
  - sphere (isotropic), [37](#), [112](#), [146](#), [155](#),  
[155–158](#), [160](#), [162–164](#), [204](#), [251](#), [272](#)
  - spheroid (axially symmetric), [36](#), [47](#), [48](#),  
[108](#), [146](#), [155](#), [155–157](#), [160](#), [251](#),  
[271](#), [272](#)
  - tensor, [146](#), [154–157](#), [159](#), [160](#), [162](#), [197](#),  
[213](#), [223](#), [250–252](#), [268](#), [271](#), [271](#),  
[272](#)
- direction cosine, [95](#), [108](#)
- display, [143](#), [147](#), [154](#), [158](#), [162](#), [178](#), [182](#),  
[186](#), [197](#), [210](#), [214–216](#), [221](#), [223](#),  
[226](#), [227](#), [229](#), [233](#), [235](#), [238](#), [244](#),  
[246](#), [258](#), [260](#)
- distribution archive, [14](#), [19](#), [121](#), [133](#)
- doc string, [122](#)
- eigenvalues, [144](#), [155](#), [156](#), [160](#), [173](#), [251](#), [272](#)
- Euler angles, [95](#), [155–157](#), [160](#), [163](#), [164](#),  
[205](#), [260](#), [262](#), [264](#), [266](#), [267](#), [272](#),  
[274](#), [275](#), [278](#)
- exponential curve fitting, [2](#)
- floating point number, [5](#), [144](#), [155–157](#), [204](#)
- function class, [6](#), [7](#)
- Gna, [17](#), [128](#)
- GNU/Linux, [14](#), [132](#)
- Google, [17](#)
- GPG
  - key, [20](#)
  - signature, [20](#)
- GPL, [1](#), [279](#)
- GUI, [9](#), [13](#), [136](#)
- help system, [5](#), [6](#), [141](#)

- indentation, [122](#)
- installation, [13](#)
- integer, [5](#), [134](#)
- keyword argument, [5](#)
- licence, [279](#)
- linking, [138](#)
- list, [5](#), [134](#)
- Mac OS X, [15](#), [132](#)
- mailing list, [17](#), [17](#), [121](#), [129](#), [137](#)
  - archive, [17](#)
  - archives, [17](#), [18](#)
  - relax-announce, [17](#), [121](#)
  - relax-commits, [17](#), [18](#), [121](#), [130](#)
  - relax-devel, [17](#), [18](#), [20](#), [23](#), [29](#), [121](#), [126](#), [127](#), [129](#), [130](#), [133](#)
  - relax-users, [17–19](#), [121](#)
- make, [132](#)
- manual
  - HTML, [17](#)
- map, [148](#), [158](#), [159](#), [166](#), [166](#), [168](#), [180](#), [181](#), [185](#), [199–203](#), [212](#), [215](#), [218](#), [260](#), [260](#), [262](#), [266](#), [266](#), [269](#), [269](#), [271](#), [276](#)
- minimisation, [5](#), [33](#), [59](#), [151](#), [156](#), [159](#), [161](#), [166](#), [169](#), [169](#), [170](#), [170](#), [171](#), [171](#), [172](#), [172](#), [173](#), [173](#), [177](#), [198–203](#), [259](#), [265](#), [268](#), [269](#)
- minimisation algorithm
  - BFGS, [40](#), [41](#)
  - Cauchy point, [42](#)
  - CG-Steihaug, [42](#)
  - coordinate descent, [40](#)
  - dogleg, [42](#)
  - exact trust region, [42](#)
  - Fletcher-Reeves, [42](#)
  - Hestenes-Stiefel, [42](#)
  - Levenberg-Marquardt, [44](#)
  - Newton, [40](#), [44](#)
  - Newton-CG, [41](#), [43](#)
  - Polak-Ribière, [42](#)
  - Polak-Ribière +, [42](#)
  - simplex, [43](#)
  - steepest descent, [40](#), [42](#), [43](#)
- minimisation techniques
  - BFGS, [60](#), [171](#), [173](#)
  - Cauchy point, [171](#)
  - CG-Steihaug, [171](#)
  - conjugate gradient, [172](#)
  - dogleg, [171](#), [172](#)
  - exact trust region, [171](#), [172](#)
  - Fletcher-Reeves, [171](#)
  - Hestenes-Stiefel, [171](#)
  - Levenberg-Marquardt, [151](#), [171](#)
  - Method of Multipliers, [169](#), [170](#), [173](#)
  - Newton, [60](#), [151](#), [169](#), [171–173](#)
  - Newton conjugate gradient, [171](#)
  - Polak-Ribière, [171](#)
  - Polak-Ribière +, [171](#)
  - simplex, [59](#), [169](#), [171](#)
  - steepest descent, [171](#)
- minisation, [2](#)
- model elimination, [2](#), [3](#), [148](#), [159](#), [161](#), [198](#), [200–203](#)
- model selection, [2](#)
  - AIC, [2](#), [148](#), [176](#), [177](#)
  - AICc, [2](#), [176](#)
  - ANOVA, [3](#)
  - BIC, [2](#), [176](#)
  - bootstrap, [2](#), [148](#), [176](#)
  - cross-validation, [2](#), [148](#), [176](#)
  - hypothesis testing, [3](#)
- model-free analysis, [33](#)
- modelling, [159](#)
- molecule, [152](#), [155](#), [156](#), [177](#), [177](#), [178](#), [178](#), [179](#), [179](#), [180](#), [198](#), [210](#), [211](#), [213](#), [225](#), [227](#), [230](#), [232–240](#), [243–249](#), [251–258](#), [262](#), [265](#), [276](#)
- Monte Carlo simulation, [3](#), [27](#), [30](#)
- MS Windows, [14](#), [132](#)
- news, [19](#)
- NMR, [147](#), [148](#), [150](#), [244](#), [257](#)
- NOE, [2](#), [21](#)
- NumPy, [13](#)
- optimise, [155](#), [198–203](#), [205](#), [213](#)
- order parameter, [161](#), [164](#), [168](#), [172](#), [180](#), [182](#), [185](#), [186](#), [204](#), [215](#), [216](#), [218](#), [221](#), [261](#), [263](#), [266](#), [270](#), [277](#)
- parameter
  - bounds, [150](#), [156](#), [158](#), [166](#), [170](#), [206](#)
  - limit, [161](#), [165](#), [169](#), [199](#), [232](#)
- parameter convolution, [88](#)
- patch, [126](#)
  - diff, [127](#)
  - Subversion, [127](#)

- PDB, [22](#), [28](#), [156](#), [157](#), [162](#), [163](#), [197](#), [198](#),  
[204](#), [207](#), [208](#), [214](#), [215](#), [223](#), [225](#),  
[250–254](#), [257](#), [258](#), [276](#)
- peak
  - height, [23](#)
  - intensity, [23](#), [27](#), [29](#)
  - volume, [23](#)
- plot, [158](#), [165](#), [166](#), [182](#), [186](#), [209](#), [210](#), [216](#),  
[221](#), [226](#)
- prompt, [4](#), [134](#)
- pyreadline, [14](#)
- Python, [1](#), [4](#), [5](#), [8](#), [10](#), [13](#), [134](#), [149](#), [159](#),  
[166](#), [169](#), [170](#), [249](#), [254](#), [258–260](#),  
[265](#), [268](#), [274](#), [276](#)
- QT, [136](#)
- read, [147](#), [153](#), [197](#), [204](#), [206](#), [210](#), [211](#), [215](#),  
[223](#), [227](#), [230](#), [235–237](#), [239](#), [240](#),  
[243](#), [244](#), [248](#), [249](#), [251](#), [253–255](#),  
[262](#), [265](#)
- reduced spectral density mapping, [2](#), [57](#)
- regular expression, [159](#), [159](#), [165](#), [166](#), [166](#),  
[170](#), [178–180](#), [233–235](#), [246–249](#), [257](#),  
[258](#), [259](#), [259](#), [260](#), [260](#), [262](#), [265](#),  
[265](#), [268](#), [268](#), [269](#), [274](#), [274](#), [276](#)
- relaxation, [148](#), [151](#), [153](#), [155](#), [166](#), [166–168](#),  
[172](#), [175](#), [211](#), [212](#), [228–232](#), [237](#),  
[260](#), [260](#), [261](#), [262](#), [264](#), [266](#), [266](#),  
[267](#), [270](#), [274](#), [274](#), [275](#), [276](#), [278](#)
- relaxation curve-fitting, [27](#)
- relaxation dispersion, [2](#)
- relaxation rate
  - cross rate, [34](#)
  - cross-relaxation, [34](#)
  - spin-lattice, [34](#)
  - spin-spin, [34](#)
- repository, [19](#), [121](#), [129](#)
  - back up, [19](#)
  - branch creation, [130](#)
  - branches, [130](#)
  - keeping up to date, [130](#)
  - merging branch back, [131](#)
  - svnmerge.py, [130](#)
- RMSD, [23](#)
- rotation, [155](#), [157](#), [164](#), [197](#), [203](#), [205](#), [223](#),  
[251](#), [252](#), [256](#)
- SciPy, [13](#)
- SCons, [20](#), [132](#)
- API documentation, [133](#)
- binary distribution, [20](#), [133](#)
- C module compilation, [132](#)
- clean up, [133](#)
- help, [132](#)
- source distribution, [133](#)
- user manual (HTML version), [132](#)
- user manual (PDF version), [132](#)
- scons, [14](#)
- Sconstruct, [13](#)
- script, [136](#)
- scripting, [8](#), [159](#), [180](#), [214](#), [236](#), [244](#)
  - sample scripts, [9](#)
  - script file, [148](#), [151](#), [159](#), [180](#), [214](#), [236](#),  
[244](#)
- sequence, [159](#), [165](#), [166](#), [170](#), [198–203](#), [213](#),  
[233–235](#), [238](#), [238](#), [239](#), [239](#), [240](#),  
[240](#), [245](#), [248](#), [252](#), [253](#), [255](#), [259](#),  
[260](#), [262](#), [265](#), [268](#), [269](#), [276](#)
- software
  - Dasha, [3](#), [16](#), [41](#), [44](#), [148](#), [151](#), [151](#),  
[152](#), [152](#)
  - Grace, [1](#), [3](#), [15](#), [24](#), [25](#), [164](#), [164](#), [165](#),  
[165](#), [166](#), [167](#), [168](#), [210](#), [226](#)
  - Modelfree, [3](#), [16](#), [44](#), [148](#), [207](#), [208](#)
  - MOLMOL, [1](#), [3](#), [16](#), [180](#), [180](#), [181](#), [181](#),  
[182–185](#), [185](#), [186–197](#), [197](#), [198](#),  
[198](#), [215](#), [215](#), [218](#), [220](#), [220](#)
  - OpenDX, [1](#), [3](#), [15](#), [158](#)
  - PyMOL, [1](#), [3](#), [16](#)
  - relax, [45](#)
  - Sparky, [23](#), [29](#), [149](#), [150](#), [242](#), [244](#), [248](#)
  - Tensor, [44](#)
  - XEasy, [23](#), [29](#), [244](#)
- spherical angles, [108](#)
- SRLS, [1](#), [2](#)
- standard deviation, [27](#)
- string, [5](#), [134](#)
- Subversion, [19](#), [121](#), [128](#)
  - book, [19](#)
  - check out, [19](#), [20](#), [131](#), [133](#)
  - commit, [131](#)
  - conflict, [131](#)
  - merge, [131](#)
  - patch, [127](#)
  - remove, [131](#)
  - svnmerge.py init, [130](#), [131](#)
  - svnmerge.py merge, [131](#)
  - svnmerge.py uninit, [131](#)



- update, [131](#)
- support request, [137](#)
- SVN, [19](#), [121](#)
- svnmerge.py, [130](#)
- symbolic link, [14](#)
  
- tab completion, [6](#)
- tar, [14](#), [212](#)
- task, [137](#)
- terminal, [4](#)
- test suite, [9](#), [128](#)
- tracker
  - bug, [137](#)
  - support request, [137](#)
  - task, [137](#)
  
- UI, [134](#)
- Unix, [132](#)
- user functions, [5](#), [6](#), [7](#), [141](#)
- user manual
  - HTML compilation, [132](#)
  - PDF compilation, [132](#)
  
- web site, [17](#)
- write, [150](#), [165](#), [211](#), [228](#), [231](#), [235](#), [236](#), [240](#),  
[258](#), [274](#)
- wxPython, [13](#)